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&
LIGNARIA
HUNGARICA

AN INTERNATIONAL JOURNAL
IN FOREST, WOOD
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Hydrological Impacts of Various Land Cover Types in the Context of Climate Change for Zala County

Péter CSÁKI* – Péter KALICZ – Gábor Béla BROLLY – Gergely CSÓKA –
Kornél CZIMBER – Zoltán GRIBOVSKI

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Abstract – The water balance of Zala County was analyzed using remote-sensing based actual evapotranspiration (ET_A) and runoff (R) in the context of land cover types. The highest mean ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forests have higher values than agricultural areas, and the lowest rates belong to artificial surfaces. Mean annual runoff is the largest on artificial surfaces (89 mm/year). For climate change impact analysis a Budyko-model was used in spatially distributed mode. The parameter of the Budyko model (α) was calculated for pixels without surplus water. For the extra water affected pixels a linear model with β parameter (actual evapotranspiration / pan evapotranspiration) was used. These parameters (α and β) can be used for evaluating future ET_A and R in spatially distributed mode. According to the predictions, the mean annual evapotranspiration may increase about 27 mm while the runoff may decrease to one third of the present amount by end of the century.

evapotranspiration / runoff / land cover / Budyko-model / climate change

Kivonat – Különböző felszínborítások vízforgalomra gyakorolt hatása a klímaváltozással összefüggésben Zala megye példáján. Zala megye területi vízmérlegének elemzése távérzékelési adatokon alapuló aktuális evapotranszspiráció (ET_A) és lefolyás (R) alapján, a felszínborítás függvényében történt. A legmagasabb átlagos párolgásértékek a vizek (658 mm/év) és a vízenyős területek (622 mm/év) esetében jelentkeztek. Az erdők magasabb párolgással jellemezhetők, mint a mezőgazdasági területek, a legalacsonyabb értékek a mesterséges felszínhez tartoznak. Az éves átlagos lefolyás a legnagyobb a mesterséges felszíneken (89 mm/év). A klímaváltozás hatásának vizsgálata egy térben osztott Budyko féle modell használatával történt. A Budyko modell kalibrációs paramétere (α) a többletvízhatástól független pixelekre került kiszámításra. A többletvízhatású pixelek esetében egy lineáris β paraméterű modellt (aktuális párolgás / kádpárolgás) vezettünk be. A két paraméter (α és β) segítségével becsülhető a jövőbeli ET_A és R, térben osztott módon. Az előrejelzés alapján az éves átlagos aktuális párolgás 27 mm-el növekedhet, míg a lefolyás a harmadára csökkenhet a század végére.

evapotranszspiráció / lefolyás / felszínborítás / Budyko-modell / klímaváltozás

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1 INTRODUCTION

More precipitation evaporates than runs off and stored on the land surface (Hewlett 1982). Generally, in Hungary about 90% of precipitation evaporates and only 10% goes to streams, soil and groundwater storage. Due to the high latent heat of vaporization value of water evapotranspiration (ET) is a very effective indicator for mass and energy () transfer between the land- or vegetation surface and the ambient atmosphere (Szilágyi – Józsa 2009).

Obtaining spatially distributed ET estimates is crucial in most water balance calculations for identifying mass and energy fluxes across the area of interest (Szilágyi – Kovács 2011). Monthly actual evapotranspiration (ET_A) has been mapped for Hungary by Kovács (2011) over the 2000-2008 period. On an annual scale – using ET_A and precipitation data – the spatially distributed runoff can be calculated using the long-term water-balance equation:

$$R = P - ET_A \quad (1)$$

where P is the precipitation, ET_A is the evapotranspiration and R is the runoff (each members in mm/period). The spatially distributed ET_A and R maps are suitable to analyze the data in the context of land cover types (CLC 2006).

2 MATERIAL AND METHODS

2.1 Description of the ET mapping technique

Morton et al. (1985) presented an algorithm (called the WREVAP model) – based on Bouchet's (1963) complementary relationship – for estimating regionally representative ET_A rates for periods longer than 5 days. Szilágyi – Józsa (2009), Szilágyi et al. (2011) devised a method of disaggregating the regional ET_A values into spatially variable ET_A rates. It is based on the assumption that at a large enough scale (for example 1 km) where surface heterogeneities of a terrain become largely smoothened out, surface temperatures are proportional to the ET_A rates, since evaporation is an endothermic process, providing an effective cooling (due to the high latent heat of vaporization) of the evaporating surface.

The spatial disaggregation of the regionally representative ET_A rates is based on a linear transformation of the 8-day composite MODIS (Moderate Resolution Imaging Spectroradiometer) daytime surface temperature (T_s) values into ET_A rates (Szilágyi – Józsa 2009). The transformation requires specifying two anchor points in the T_s – ET plane (*Figure 1*). The first is defined by the spatially averaged daytime surface temperature (T_s) and the corresponding regionally representative ET_A rate (from WREVAP, using spatially averaged values of the required climate variables). The second anchor point comes from a spatial average of the coldest pixel values for well watered cells within the region (T_{ws} – wet surface temperature) and the corresponding wet environment evaporation rate (ET_w), out of consideration that the coldest pixels are the wettest (Szilágyi – Kovács 2010). The two points define the linear transformation of the T_s pixel values into ET_A rates for the examined period (for example a month).

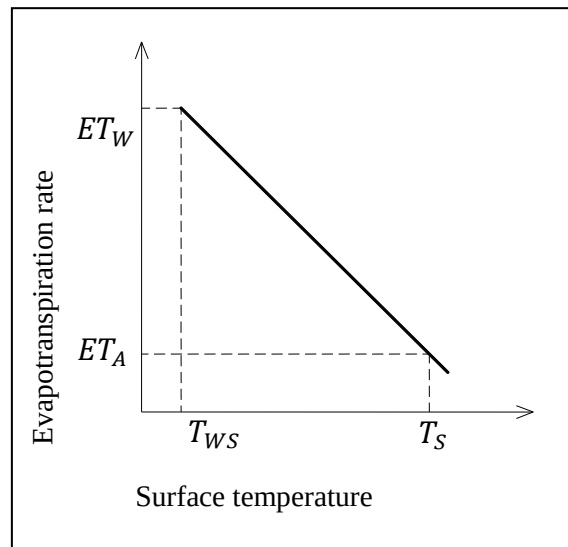


Figure 1. Schematic representation of the linear transformation of the MODIS daytime surface temperature values into ET rates (after Szilágyi et al. 2011)

The 8-day composited MODIS daytime T_s data for Hungary over the 2000–2008 period was collected and the T_s maps were averaged for each month to yield one surface temperature map per month by Kovács (2011). Further necessary data for calculation (mean annual precipitation, mean monthly air temperature, specific humidity as well as sunshine duration values) were provided by the Hungarian Meteorological Service. The monthly ET_A maps were prepared from March till November each year, because in the winter-time with possible patchy snow cover on the ground the quasi-constant surface net energy assumption of the T_s versus ET_A transformations break down (due to the snow cover's vastly different albedo from that of the land) (Szilágyi – Józsa 2009). ET in Hungary is small from December through February, the sum total is about 20 mm (Kovács 2011). We made calculations for total water years (from November 1 to October 31), so a 20 mm correction was added for all pixels of each mean annual ET maps (1999 November was prepared as the average of the other Novembers). The mean annual ET maps were averaged for the period of 1999–2008.

2.2 The Budyko type model

The Budyko curve (Budyko 1974) is often used to estimate the actual evaporation as a function of the aridity index. In any location, depending on the dryness of the climate, either the available water or the available energy is the limiting factor (Gerrits et al. 2009).

The Budyko curve is based on two balance equations, the water balance and the energy balance:

$$\Delta S = P - ET_A - R \quad (2)$$

$$Q_{nT} = L \cdot ET_A + H + G \quad (3)$$

where ΔS is the water storage change over time (m/year), P the precipitation (m/year), ET_A the actual evaporation (m/year), R the runoff (m/year), Q_{nT} the net radiation ($J/m^2/year$), L the latent heat of vaporization (J/m^3), H the sensible heat flux ($J/m^2/year$), and G the ground heat flux ($J/m^2/year$).

On an annual time scale we can assume (Arora 2002) that the water storage change is negligible ($\Delta S = 0$) and that the net ground heat flux approaches zero ($G = 0$), thus:

$$P = ET_A + R \quad (4)$$

$$Q_{nT} = L \cdot ET_A + H \quad (5)$$

By dividing Eq. 5 by Eq. 4 we obtain:

$$\frac{Q_{nT}}{P} = \frac{L \cdot ET_A}{P} + \frac{H}{P} \quad (6)$$

Arora (2002) interprets potential evaporation as (different from the above ET_p):

$$ET_0 = \frac{Q_{nT}}{L} \quad (7)$$

Displacement of Eq. 6 by Eq. 7:

$$\frac{ET_0}{P} = \frac{ET_A}{P} + \frac{(H/L)}{P} \quad (8)$$

If we define the Bowen ratio as $B_r = H/L \cdot ET_A$ (Gerrits et al. 2009), we obtain:

$$\frac{ET_0}{P} = \frac{ET_A}{P} + \frac{B_r \cdot ET_A}{P} = \phi = \frac{ET_A}{P} (1 + B_r) \quad (9)$$

with ϕ the aridity index.

Since the Bowen ratio can also be expressed as a function of the aridity index ($B_r = f(\phi)$) (Arora 2002), Eq. 9 can be rewritten as:

$$\frac{ET_A}{P} = \frac{\phi}{1+f(\phi)} = f(\phi) \quad (10)$$

So, the evapotranspiration ratio $\left(\frac{ET_A}{P}\right)$ is a function of aridity index.

A lot of studies have been done on finding this relation. The best-known classical studies were done by Schreiber, Ol'dekop, Turc, Pike, Budyko and Porporato et al. (Gerrits et al. 2009). Their equations are summarized in Table 1.

Table 1. Equations for the relation of the evapotranspiration ratio $\left(\frac{ET_A}{P}\right)$ and the aridity index (ϕ) (after Gerrits et al. 2009)

Equation	Reference
$\frac{ET_A}{P} = 1 - \exp(-\phi)$	Schreiber (1904)
$\frac{ET_A}{P} = \phi \tanh(1/\phi)$	Ol'dekop (1911)
$\frac{ET_A}{P} = \frac{1}{\sqrt{0.9+(1/\phi)^2}}$	Turc (1954)
$\frac{ET_A}{P} = \frac{1}{\sqrt{1+(1/\phi)^2}}$	Pike (1964)
$\frac{ET_A}{P} = [\phi \tanh(1/\phi)(1 - \exp(-\phi))]^{0.5}$	Budyko (1974)
$\frac{ET_A}{P} = 1 - \frac{\phi \cdot \gamma^{\frac{\gamma}{\phi}-1} \exp(-\gamma)}{\Gamma(\frac{\gamma}{\phi}) - \Gamma(\frac{\gamma}{\phi}, \gamma)}$	Porporato et al. (2004)

From the above models we are using the Schreiber equation (Schreiber 1904), because of its simplicity. The actual evapotranspiration estimated by Schreiber's method (hereinafter the evapotranspiration, the precipitation and the runoff are understood in mm/year instead of m/year):

$$ET_A = P(1 - \exp(-\phi)) = P \left(1 - \exp\left(-\frac{ET_0}{P}\right)\right) \quad (11)$$

The determination of runoff by Schreiber (Fraedrich 2009):

$$R = P - ET_A = P \exp\left(-\frac{ET_0}{P}\right) \quad (12)$$

After rearrangement we get the following equation for potential evapotranspiration:

$$ET_0 = -P \left(\ln\left(\frac{R}{P}\right) \right) \quad (13)$$

ET_0 can also be expressed as a function of pan-evaporation (ET_{pan}), according to the general relation for Hungary (Nováky 2002):

$$ET_0 = f(ET_{pan}) = -\alpha ET_{pan} = -\alpha \left(36400 \frac{T}{P} + 104 \right) \quad (14)$$

where α is a calibration parameter, which aggregates all of the factors affecting ET (dominantly the surface cover) (Keve – Nováky 2010), and T is the mean annual temperature (°C).

Knowing the above equations, α can be calculated:

$$\alpha = -\frac{ET_0}{ET_{pan}} \quad (15)$$

According to Nováky, the spatially distributed version of the Budyko model is applicable to analyze the climatic impacts (Nováky 1985, 2002). The spatially-distributed determination of α parameter was the following: ET_0 (Eq. 13) and ET_{pan} (the part in parentheses of Eq. 14) values of Zala county were calculated for the 1999-2008 period (in the same resolution as the ET_A maps), and they were substituted for Eq. 15.

When the ET_A value was higher than the P value of the pixel, so R became negative, the α parameter could not be determined, because the natural logarithm of a negative number is undefined (Eq. 13). For these pixels another calibration parameter (β) was calculated according to the next formula (McMahon et al. 2012):

$$\beta = \frac{ET_A}{ET_{pan}} \quad (16)$$

α and β parameters must be calculated in spatially distributed mode (maps). The parameter maps (α and β) are suitable to analyze this data in the context of land cover types. They can be used for evaluating future ET and R in spatially-distributed mode, for that only temperature and precipitation predictions are required.

The calculations were done with the help of DigiTerra Map software, the temperature and precipitation data were available in the “Agroclimate 2 (VKSZ_12-1-2013-00-34)” project.

3 STUDY SITE DESCRIPTION

Zala County is situated in the south-western part of Hungary (Figure 2). It is one of the smallest counties of Hungary. It covers 3784 km². The population was 282 179 people in 2011 (less than the 3% of the total population of Hungary). The mean population density is 75 people per km² (KSH 2011).

The county has a varying landscape of hills and valleys. The settlement density is one of the highest in Hungary, although the average size of the settlements is less than the half of the national average. It has no distinctive isolation from adjacent territories. It is a transition through a series of grades. The highest point of the county is 445 m (Köves-tető) in the Keszthelyi Mountains on the eastern edge of the county.



Figure 2. Location of Zala County within Hungary

The climate is moderated by atlantic effects, so the mean annual temperature was about 11.6 °C between 1999 and 2008. Winters are relatively mild and summers tend to be cooler than the norm for the Carpathian Basin. It is one of the wettest parts of the country. The average annual rainfall during this period was about 700 mm in the west, and 600 mm in the east.

Agriculture is the dominant land use (54%) in the County, with a significant presence of forest and semi natural areas, which cover more than 37% of the total area (Figure 3 and Table 2).

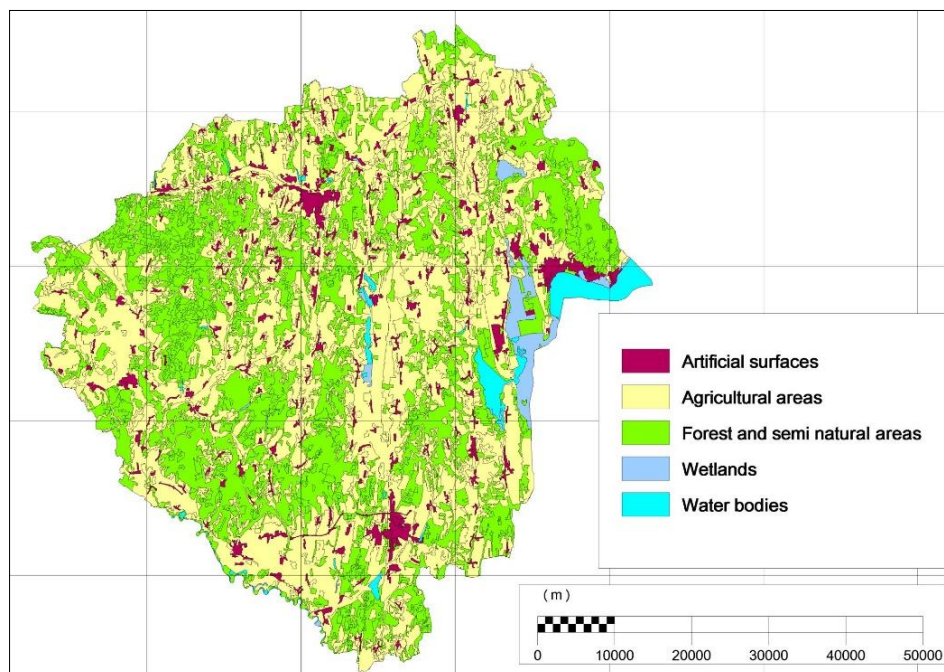


Figure 3. Land cover of Zala County (CLC 2006)

Table 2. Land cover distribution of Zala County

Land cover type	Area (km ²)	Percentage (%)
Artificial surfaces	195.90	5.18
Agricultural areas	2040.71	53.94
Forest and semi natural areas	1406.01	37.16
Wetlands	62.97	1.66
Water bodies	77.94	2.06
Total	3783.54	100.00

4 RESULTS

The averaged (1999-2008 period) mean actual evapotranspiration and runoff for Zala County were analyzed in the context of land cover types. Moreover, the Budyko type α and the β parameters were calculated, mapped and analyzed too.

4.1 Evaluation of evapotranspiration

The mean annual actual evapotranspiration over Zala County (1999-2008) is displayed in Figure 4. The average ET_A of the County was 577 mm/year, which is 88% of the mean annual precipitation (655.7 mm/year). The brown pixels show lower rates on the map. The bigger cities are distinctly visible as brown patches. Higher ET_A values (blue pixels) belong to water bodies and wetlands,.

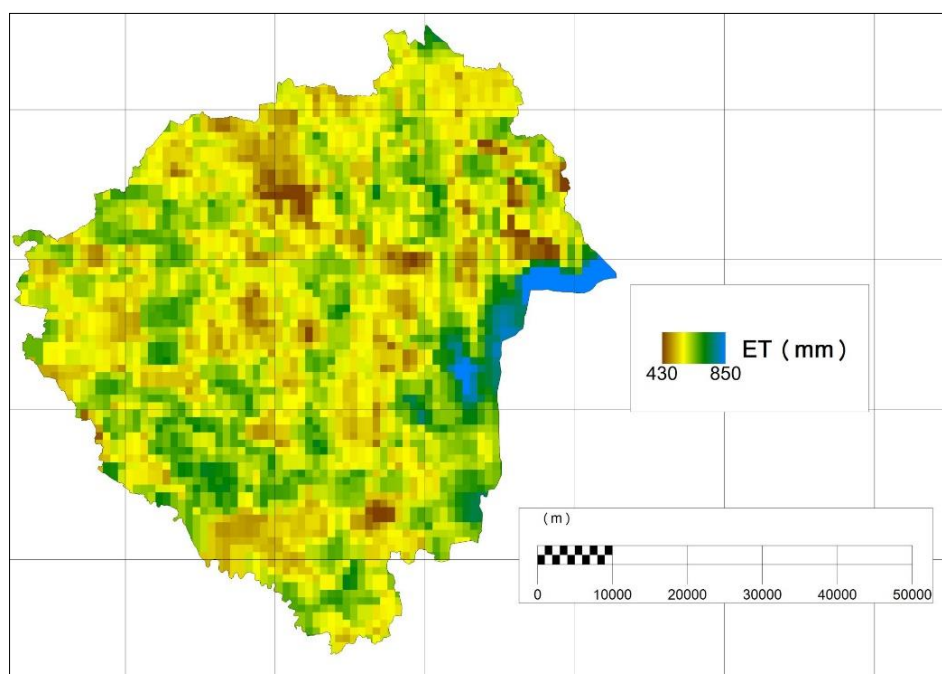


Figure 4. Mean annual ET_A rates over Zala County (1999-2008)

Table 3 contains the ET_A values belonging to the each Corine Land Cover (CLC 2006) type. The evapotranspiration, the runoff, the Budyko α and the β parameter maps have a 1·1 km resolution. They were examined with a vector land cover map, so more land cover types might belong to one pixel. The value of these 'mixed pixels' were counted in more land cover types, so it distorts the differences between the categories.

The highest mean annual ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forest and semi natural areas have higher values than agricultural areas and the lowest rates belong to artificial surfaces. Standard deviation is the highest in case of water bodies (97 mm).

Table 3. Mean annual ET_A rates of different land cover types over Zala County (1999-2008)

Land cover type	Mean annual ET (mm)				
	Min	Max	Average	P%*	Std. dev
Artificial surfaces	450	703	562	86	38
Agricultural areas	434	721	569	87	35
Forest and semi natural areas	434	828	582	89	37
Wetlands	461	729	622	95	53
Water bodies	486	846	658	100	97

* In the percentage of the mean annual precipitation

Figure 5 shows the mean annual ET_A over forest and semi natural areas. In the north-eastern part of Zala County the ET_A values of forest are generally lower than the south-western part and the neighborhood of wetlands.

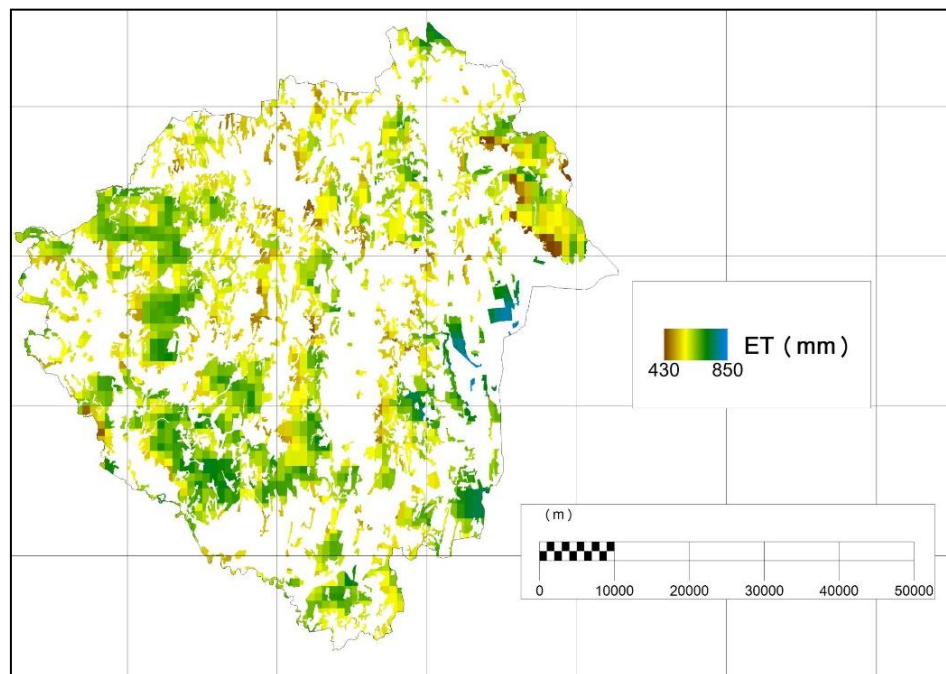


Figure 5. Mean annual ET_A rates over forest and semi natural areas in Zala County (1999-2008)

4.2 Evaluation of runoff

The mean annual runoff (R , 1999–2008) was calculated from the water-balance equation, as the difference of annual precipitation and mean annual actual evapotranspiration ($R = P - ET_A$). The 10×10 km spatial resolution precipitation map was downscaled for 1×1 km using the bicubic convolution interpolation technique, and after it was validated by field measurements. (The data from field measurements were not used for preparation of the original map.)

Figure 6 shows the mean annual runoff over Zala County and Table 4 contains the rates of the different types of land cover. The average runoff was 78 mm/year, which is 12% of the mean annual precipitation (655.7 mm/year). The runoff is the highest on artificial surfaces, and it decreases in the other categories. It is especially low for wetlands, and negative for water bodies, where the ET_A is generally higher than the precipitation. Moreover, the standard deviation is the highest over water bodies (119 mm).

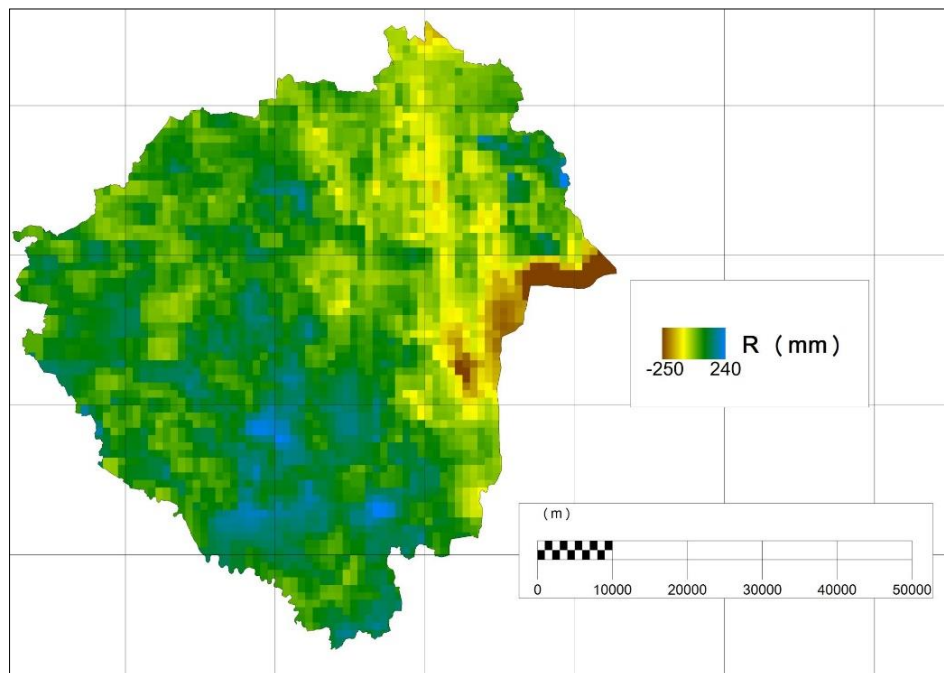


Figure 6. Mean annual R rates over Zala County (1999–2008)

Table 4. Mean annual runoff rates of different land cover types over Zala County (1999–2008)

Land cover type	Mean annual R (mm)				
	Min	Max	Average	P%*	Std. dev
Artificial surfaces	–86	231	89	14	48
Agricultural areas	–88	231	87	13	45
Forest and semi natural areas	–181	214	77	12	46
Wetlands	–98	140	2	0	58
Water bodies	–250	211	–19	–3	119

* In the percentage of the mean annual precipitation

4.3 Evaluation of α and β parameters

The calculated Budyko type α parameter can be seen in Figure 7, and the values belonging to the each land cover type are in Table 5.

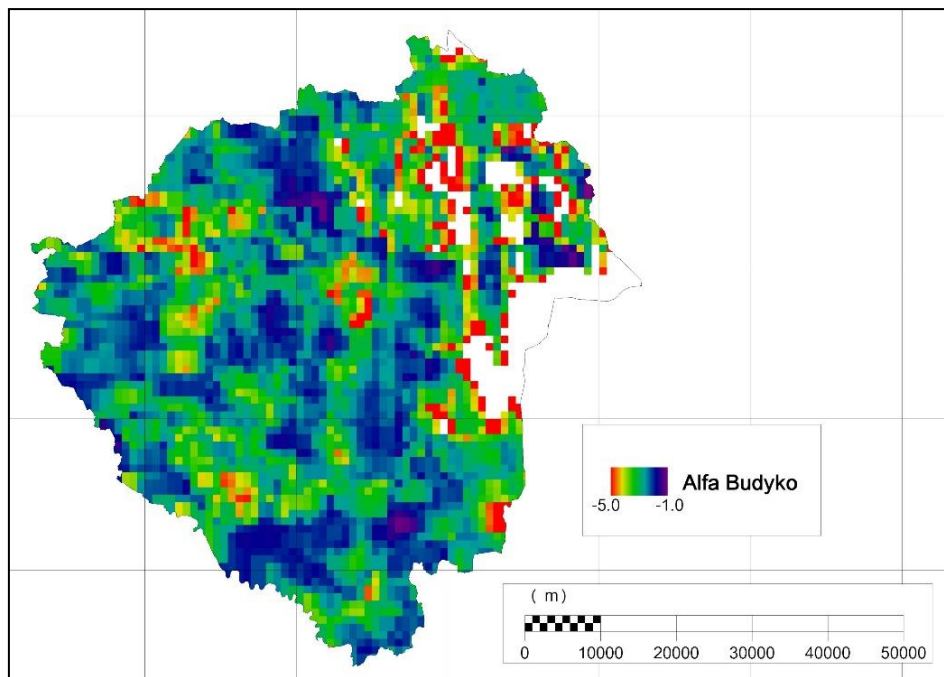


Figure 7. The calculated Budyko type α parameter rates in Zala County

Table 5. The calculated Budyko type α parameters (absolute values) of different land cover types over Zala County

Land cover type	α parameter			
	Min	Max	Average	Std. dev.
Artificial surfaces	1.03	4.59	1.80	0.42
Agricultural areas	0.96	7.48	1.86	0.46
Forest and semi natural areas	0.96	7.48	1.98	0.51
Wetlands	1.08	5.88	2.42	1.05
Water bodies	1.15	6.30	2.16	0.87

Compared to the α values determined by Keve – Nováky (2010), the comparable categories according to land cover types show similar tendencies (Table 6), but the differences between the categories are smaller. High absolute α values are calculated for forest, lower for agricultural areas and much lower for artificial surfaces. The α parameters are not comparable for wetlands and water bodies. The deviation from the values estimated by Keve and Nováky arises from two sources. The first reason is the different climatic conditions because they modelled a plain catchment basin, second is that the values of their parameters were not based on calculations but on estimations considering the land cover.

Table 6. α values determined by Keve – Nováky (2010)

Description	α
Artificial surface, with channel	2.3
More channels in the area	2.4
Big channel in the area	2.5
Agricultural area, with channel	2.7
Agricultural area, without channel	2.8
Area far from channel, forest	2.9

We calculated the β parameter (which gives the relationship between ET_{pan} and ET_A) for those pixels, where ET_A value was higher than P value, because the Budyko type model for this type of pixels is not valid. Typically this is the case for wetlands and water bodies. The β parameter map is displayed in *Figure 8*, and the rates of the different land cover types can be seen in *Table 7*. From agricultural areas to water bodies, β shows increasing values. (For artificial surfaces it is inadequate, because the pixel number of the category was very small.) The highest maximum values were detected over water bodies (1.08) as well as forest and semi natural areas (1.07), exceeding the calculated pan-evaporation (U_{pan}) rates by 7–8%.

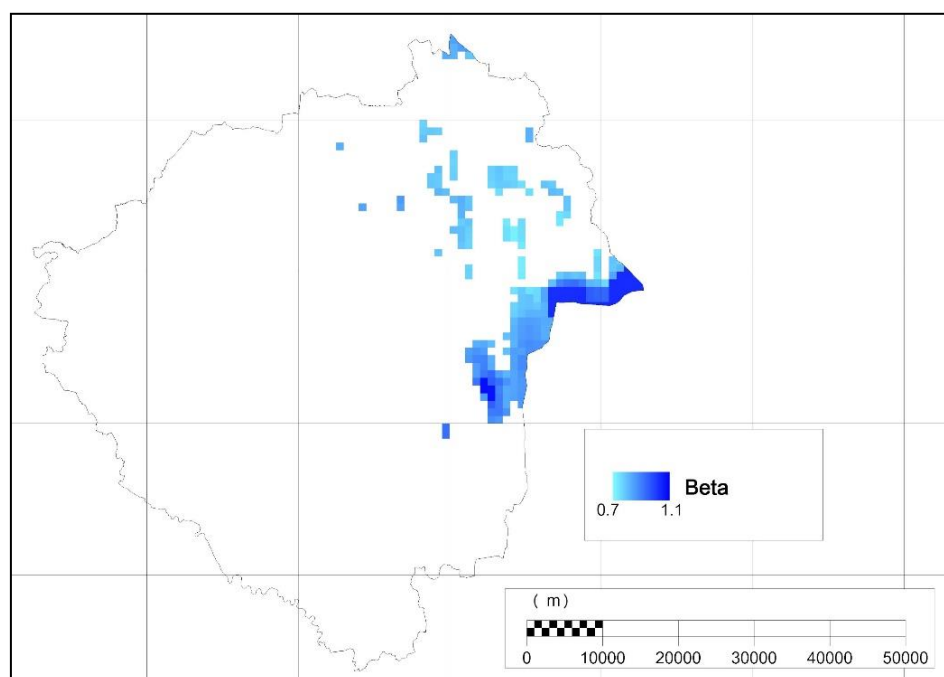


Figure 8. β parameter pixels and rates in Zala County

Table 7. The calculated β parameter rates of different land cover types over Zala County

Land cover type	β parameter			
	Min	Max	Average	Std. dev.
Artificial surfaces	0.71	0.91	0.80	0.05
Agricultural areas	0.71	0.93	0.79	0.05
Forest and semi natural areas	0.71	1.08	0.80	0.06
Wetlands	0.72	0.98	0.82	0.05
Water bodies	0.76	1.08	0.92	0.10

5 EVAPOTRANSPIRATION AND RUNOFF PREDICTIONS

Temperature and precipitation data were required for estimating future ET_A and runoff of Zala County, besides the prepared Budyko- α and β parameter maps. They were obtained for three periods (2011–2040, 2041–2070, 2071–2100) by averaging of 12 Regional Climate Models data (RCM, *Table 8*, Csóka 2013). The original grid size of the RCM maps was 25×25 km. They were disaggregated to 1×1 km spatial resolution by the bicubic convolution interpolation technique.

Table 8. Main parameters of the Regional Climate Models (Csóka 2013)

Nr.	Institute	Model	Scenario	Resolution
1.	C4I	RCA3	A1B	25 km
2.	MPI-M	REMO	A1B	25 km
3.	ETHZ	CLM	A1B	25 km
4.	KNMI	RACMO2	A1B	25 km
5.	DMI	HIRHAM5	A1B	25 km
6.	DMI	HIRHAM5	A1B	25 km
7.	SMHI	RCA	A1B	25 km
8.	SMHI	RCA	A1B	25 km
9.	SMHI	RCA	A1B	25 km
10.	HC	HadRM3Q0	A1B	25 km
11.	HC	HadRM3Q3	A1B	25 km
12.	HC	HadRM3Q16	A1B	25 km

The 11, 14, 15 and 16 Equations were used for calculating spatially distributed future ET_A . The runoff data were obtained as the difference of precipitation and ET_A . These calculations were done for Zala County, not on a catchment scale.

Figure 9 shows the estimated mean annual ET_A values belong to the period 1999–2008 and the three predicted periods (2011–2040, 2041–2070, 2071–2100) in the context of climatic index ($100 \cdot T/P$, Nováky 1985). According to the predictions a mean annual temperature increase of about 3 degrees (from 11.6 °C to 14.6 °C) and a 25 mm decrease in precipitation can be expected by the end of the century. The mean annual evapotranspiration may increase by about 27 mm, from 577 mm to 604 mm (from 88 to 96 percent of the precipitation).

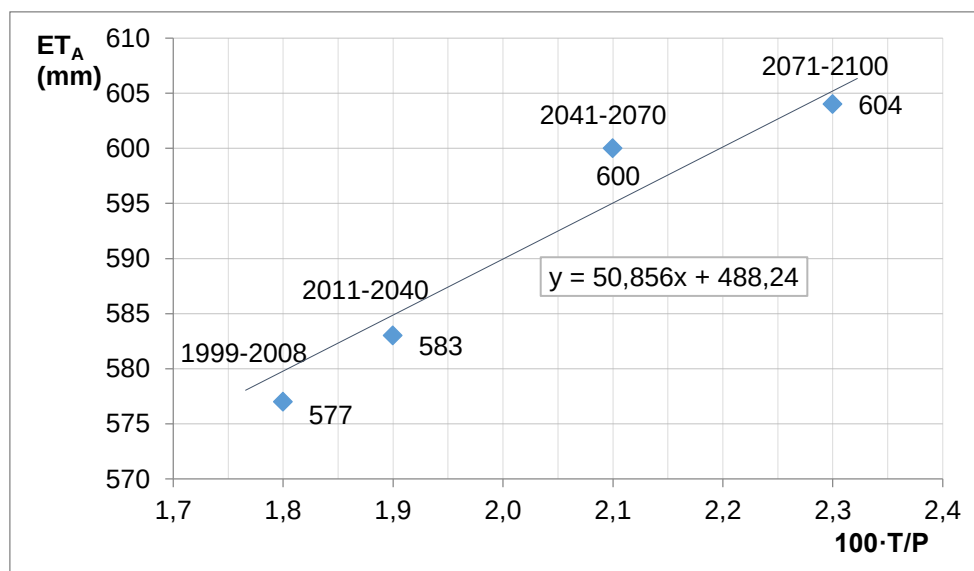


Figure 9. The trend of the mean annual evapotranspiration in the context of the climatic index ($100 \cdot T/P$)

Table 9 contains the estimated mean annual ET_A values belonging to each land cover type. The largest increase (90–100 mm) can be expected in wetlands and water bodies. The

ET_A increments are similar for artificial surfaces, agricultural areas, forest and semi-natural areas.

Table 9. The annual actual evapotranspiration of different land cover types, and annual precipitation, mean annual temperature and climatic index for the 1999–2008 period and for three future periods

Period	Mean annual ET _A (mm)					P (mm)	T (°C)	100·T/P
	AS*	ACA	FSN	WL	WB			
1999–2008	562	569	582	622	658	655.7	11.6	1.8
2011–2040	567	574	586	646	684	642.6	12.3	1.9
2041–2070	583	590	602	677	718	648.7	13.5	2.1
2071–2100	585	592	604	714	759	630.4	14.6	2.3
Slope [#]	45.730	43.524	44.213	167.610	182.730	–	–	–

* AS: artificial surfaces, ACA: agricultural areas, FSN: forest and semi natural areas, WL: wetlands, WB: water bodies.

[#]Slope of the trend line.

Figure 10 shows the mean annual runoff values belonging to the 1999-2008 period and the three predicted periods in the context of climatic index. The mean annual runoff may significantly decrease (from 78 mm/year to 27 mm/year, from 12 to 4 percent of the precipitation) by the end of the 21st century.

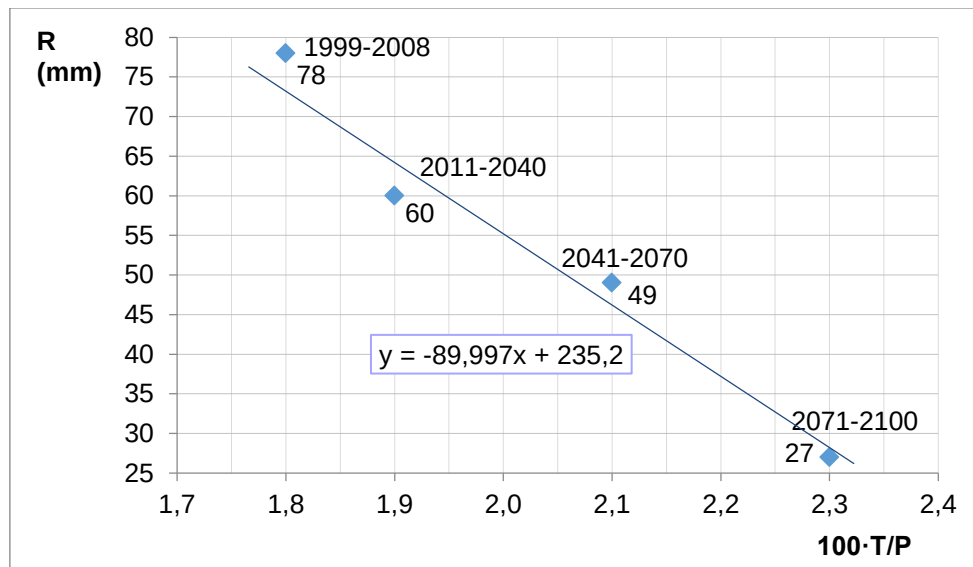


Figure 10. The trend of the mean annual runoff in the context of the climatic index (100·T/P)

The estimated mean annual runoff values belonging to the each land cover type are shown in Table 10. Obviously the increasing evapotranspiration prevails in case of the wetlands and water bodies: –144 mm and –115 mm negative water balance can be detected for future. If we compare artificial surfaces, agricultural areas as well as forest and semi natural areas, for the latter the lowest annual runoff is calculated.

Table 10. The annual runoff of different land cover types, and annual precipitation, mean annual temperature and climatic index for the period of 1999–2008 and for three future periods

Period	Mean annual R (mm)					P (mm)	T (°C)	100·T/ P
	AS*	ACA	FSN	WL	WB			
1999–2008	89	87	77	2	–19	655.7	11.6	1.8
2011–2040	71	69	59	–36	–58	642.6	12.3	1.9
2041–2070	61	59	50	–61	–86	648.7	13.5	2.1
2071–2100	40	39	29	–115	–144	630.4	14.6	2.3
Slope [#]	–84.625	–83.215	–83.281	–205.770	–220.090	–	–	–

* AS: artificial surfaces, ACA: agricultural areas, FSN: forest and semi natural areas, WL: wetlands, WB: water bodies.

[#] Slope of the trend line.

6 CONCLUSIONS

The spatially-distributed ET_A and runoff maps are suitable to analyze the data in the context of land cover types. The average ET_A of Zala County from 1999–2008 was 577 mm/year, or 88% of the mean annual precipitation (655.7 mm/year). The highest mean annual ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forest and semi natural areas have higher values than agricultural areas. The lowest rates belong to artificial surfaces. The mean annual runoff is the largest on artificial surfaces (89 mm/year), and it decreases on the other land cover types.

We used the Budyko type model (α parameter) and a linear model with β parameter for evaluating the effects of climate change on evapotranspiration. The β parameter was used for the extra water affected pixels. These calculations were not done on a watershed, but in the future the α and β parameters can be validated on a catchment scale using historical precipitation and streamflow measurements. By using the two parameter maps and future data of climate models (mean annual temperature and precipitation) evapotranspiration and runoff predictions have been made until the end of the 21st century. According to the predictions, the mean annual evapotranspiration may increase about 27 mm while the runoff may decrease to the one third of the present amount by the end of the century.

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Detecting Trends in the Annual Maximum Discharges in the Vah River Basin, Slovakia

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Abstract – A number of floods have been observed in the Slovak Republic in recent years, thereby raising awareness of and concern about flood risks. The paper focuses on the trend detection in the annual maximum discharge series in the Vah River basin located in Slovak Republic. Analysis was performed on data obtained from 59 gauging stations with minimum lengths of the observations from 40 years to 109 years. Homogeneity of the time series was tested by Alexandersson test for single shift at 5% level of significance. The Mann-Kendall trend test and its correction for autocorrelated data by Hamed and Rao (1998) were used to analyse the significance of detected changes in discharges. The series were analysed at different lengths of 40, 50, 60 years and whole observation period. Statistically significant rising and decreasing trends in the annual maximum discharge series were found in different regions of the Vah River catchments.

maximum annual discharges / homogeneity / Mann-Kendall trend test

Kivonat – Az évi maximális vízhozamok trend elemzése a Vág (Vah) vízgyűjtőjében, Szlovákiában. Az árhullámok száma igen jelentős napjainkban a Szlovák Köztársaságban, ezért egyre nagyobb az igény az árvízi kockázat elemzésekre. Jelen tanulmány az évi maximális vízhozamok tendenciájának elemzésére koncentrál a Szlovák Köztársaságban található Vág vízgyűjtőjében. Az elemzés alapját 59 vízmérce állomás idősoros adatai adták, amely idősorok hossza 40-től 109 évig változott. Az idősorok homogenitása Alexandersson tesztel lett értékelve 5%-os megbízhatósági szinten. A vízhozamban bekövetkező változások szignifikanciájának elemzésére Mann-Kendall tesztet, illetve annak Hamed és Rao (1998) által továbbfejlesztett, autokorrelált adatokra értelmezett változatát használtuk. Az idősorokat egységes hosszakban, 40, 50, 60 év, és a teljes észlelési időszakra vonatkozóan is értékeltük. Az eredmények alapján statisztikailag szignifikáns emelkedő és csökkenő trendek is kimutathatók voltak a maximális évi vízhozamokban a Vág vízgyűjtőjének különböző régióiban.

évi maximális vízhozam / homogenitás / Mann-Kendall trend teszt

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1 INTRODUCTION

A number of floods have been observed around Europe in recent decades, which have raised awareness of and concerns about flood risks. The observation and detection of changes in long-term hydrological time series is important for scientific and practical reasons, especially when designing water management structures.

There is a need to understand hydrological processes on small and also large temporal and spatial scales, land-atmosphere interactions, land use and climate change impacts (Szolgay, 2011). Further Blöschl et al. (2007) discuss the scales of climate variability and land cover change impact on flooding. In the note they debate, that climate change impact is likely to occur at large scales and to be consistent in both small and large catchments and regions, while land cover change is usually a local phenomenon, which effects are decreasing at larger spatial scale. Therefore the major driving forces behind hydrological phenomena can vary depending on the factor and spatial scale

Many studies dealing with analyses of trends concerning floods have been published; many of them have found decreasing or increasing trends in their magnitudes and occurrences, and many have also found no changes (Strupczewski et al. 2001, Xiong – Guo 2004, Delgado et al. 2010, Armstrong et al. 2012, Rougé et al. 2013). The Mann-Kendall test (Kendall 1975, Kliment et al. 2011, Armstrong, 2012) is widely used in engineering hydrology to detect trends. When the data do not follow the normal distribution or are autocorrelated, authors have suggested the use of test corrections (Douglas et al. 2000, Burn – Hag Elnur 2001, Zhang et al. 2001, Yue et al. 2002, Lang 2012, Seoane – Lopez 2007, Danneberg 2012).

Strupczewski et al. (2001) investigated trends in 70-year-long observations of the annual maximum flows of Polish rivers. A decreasing tendency in the mean and standard deviations of annual peak flows was found with the use of the maximum likelihood method for estimating parameters and the Akaike Information Criterion for identification of an optimum model. Xiong and Guo (2004) tested maximum annual discharge series, including the mean annual maximum of the Yangtze River during a 120-year-long time period. No significant trend at the 5% significance level was found by the use of the Mann-Kendall test and Spearman's rho at the tested station. Delgado et al. (2010) examined over 70-year-long annual maximum discharge series from 4 gauging stations in the Mekong river in Southeast Asia with use of Mann Kendal test, ordinary least squares with resampling and non-stationary generalised extreme value functions. The results of the study pointed out increasing likelihood of extreme floods during the last half of century. They also concluded that the absence of detected positive trends was a result of methodological misconception due to simplistic models.

Armstrong et al. (2012) analysed peak over threshold data with a recorded average period of 71 years. An increasing trend was found with the use of the Mann-Kendall trend test in 22 stations out of the 23 investigated, and a hydroclimatic shift towards a rising number of flood occurrences was found. Rougé et al. (2013) studied trend and step-change detection methods in hydrological time series (rainfall, river flows) and applied a combined Mann-Kendall and Pettitt test (1979) on 1217 data sets in the United States during the years 1910–2009.

In Slovakia, a long-term annual time series was investigated by Pekarova et al. (2008). In a IHP UNESCO report (Pekarova et al., 2008), daily discharges of the Danube River from 1976–2005 were analysed, and a rising tendency was detected, but no change was found in the annual and monthly time series. The Mann-Kendall trend test was used in Tegelhoffova (2012) to detect trends in the average annual and monthly discharges in Slovak rivers. However, no thoughtful trend analysis of annual maximum discharges in Slovak catchments has been provided.

This paper focuses on a time series analysis and significance assessment of trends detected in annual maximum discharge series in the Vah River catchment in the Slovak Republic and the lessons learned concerning the occurrence of extreme discharges in the Vah River catchments. The paper is organised as follows: methodology, input data description, results and discussion, and conclusions.

2 METHODS

In engineering hydrology, time series analysis usually operates under the assumption of homogeneity, stationarity and independence of time series. Homogeneity in the time series can be tested by Alexandersson test (Alexandersson – Moberg 1997), which is able to detect abrupt changes in analysed data set. We used Alexandersson test (Standard normal homogeneity test, SNHT) for single shift programmed in AnClim software (Stepanek 2007).

The significance of monotonic linear trend present in the time series is possible to assess by Theil (1950) and Sen (1968) slope defined as:

$$\beta = \text{Median} \left(\frac{x_j - x_l}{j - l} \right) \forall l < j, \quad (1)$$

where β is the estimate of slope of the trend and x_j is value of observation from $j = 1 \dots l$. Positive value of β reveals increasing trend, negative value is sign of decreasing trend.

Changes in a trend can be detected by a rank-based, non-parametric Mann-Kendall trend test for monotonic trends (WMO 2000).

The test statistic S equals to (Yue et al. 2012):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k), \quad (2)$$

where x_j are the values of the data; n is the length of the time series and

$$\begin{aligned} \text{Sign}(x_j - x_k) &= 1, \text{ if } x_j - x_k > 0 \\ &= 0, \text{ if } x_j - x_k = 0 \\ &= -1, \text{ if } x_j - x_k < 0. \end{aligned} \quad (3)$$

In case the time series has $n \geq 8$, the statistic S has and almost normal distribution, and its variance is computed as:

$$\text{VAR}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p+5)], \quad (4)$$

where g is the number of tied groups, and t_p is the amount of data with the same value in the group $p=1 \dots g$.

The normalised test statistic Z :

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{for } S < 0 \end{cases} \quad (5)$$

If the normalised test statistic Z is equal to zero, the data are normally distributed, and the positive values of Z mean a rising trend and negative a decreasing trend (Yue et al. 2012).

The p-value is computed as:

$$p = 0,5 - \Phi(|Z|) \text{ kde } \Phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-\frac{t^2}{2}} dt. \quad (6)$$

If the data are not independent a correction of the MK trend test should be used. Autocorrelation can influence the results of the analysis (Lang 2012, Yue et al. 2002). Hamed and Rao (HR) (1998) correction addresses the issue of autocorrelation in the time series. The modified MK equation for any variance is:

$$V^*(S) = \text{VAR}(S) \frac{n}{n^*}, \quad (7)$$

where $\text{VAR}(S)$ is a variance from the original MK test (4); n is the length of the time series; n^* is the effective number of observations and $\frac{n}{n^*}$ is the correction factor in the case of autocorrelation in the sample.

The modified MK statistic:

$$Z^* = \begin{cases} \frac{S-1}{\sqrt{V^*(S)}} & \text{pre } S > 0 \\ 0 & \text{pre } S = 0. \\ \frac{S+1}{\sqrt{V^*(S)}} & \text{pre } S < 0 \end{cases} \quad (8)$$

The correction factor can be calculated as:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{j=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_k^R, \quad (9)$$

where r_k^R is the autocorrelation function of the ranks of the observations. It can also be calculated by the equation by Salas et al. (1980):

$$r_k = \frac{\frac{1}{n-k} \sum_{t=1}^{n-k} (X_t - E(X_t))(X_{t+k} - E(X_{t+k}))}{\frac{1}{n} \sum_{t=1}^n (X_t - E(X_t))^2}, \quad (10)$$

where

$$E(X_t) = \frac{1}{n} \sum_{t=1}^n X_t, \quad (11)$$

where r_k is the correction factor for the data X_t ; $E(X_t)$ is the average of the input data.

Hamed and Rao (1998) also suggest using only statistically significant values of r_k , because other values have a negative influence on the values of variance S .

The null hypothesis of the MK and HR tests states that there is no perceptible trend in the sample data. If the resulting p-value is lower than level of significance, then we can reject the null hypothesis (Diermanse et al. 2010).

The Sen's slope and trend analysis tests were programmed and performed in the R free software programming language using the fume and Kendall packages (McLeod 2011, Santahter Meteorology Group 2012, R Core Team 2013).

3 INPUT DATA

Annual maximum discharges from 59 gauging stations in the Vah River basin (*Figure 1*) were obtained from the Slovak Hydrometeorological Institute in Bratislava, Slovakia. The annual maximum discharge series for the trend analysis chosen are based on the length of the observations, which is more than 40 years, with a maximum length of 109 years. Annual maximum discharges represent the observed peak maximum values during hydrological year. Mean record length of data set was 53.9 years, median 48 years and mode 41 years. *Table 1* summarised the selected gauging stations with starting year of observation in the Vah River basin.

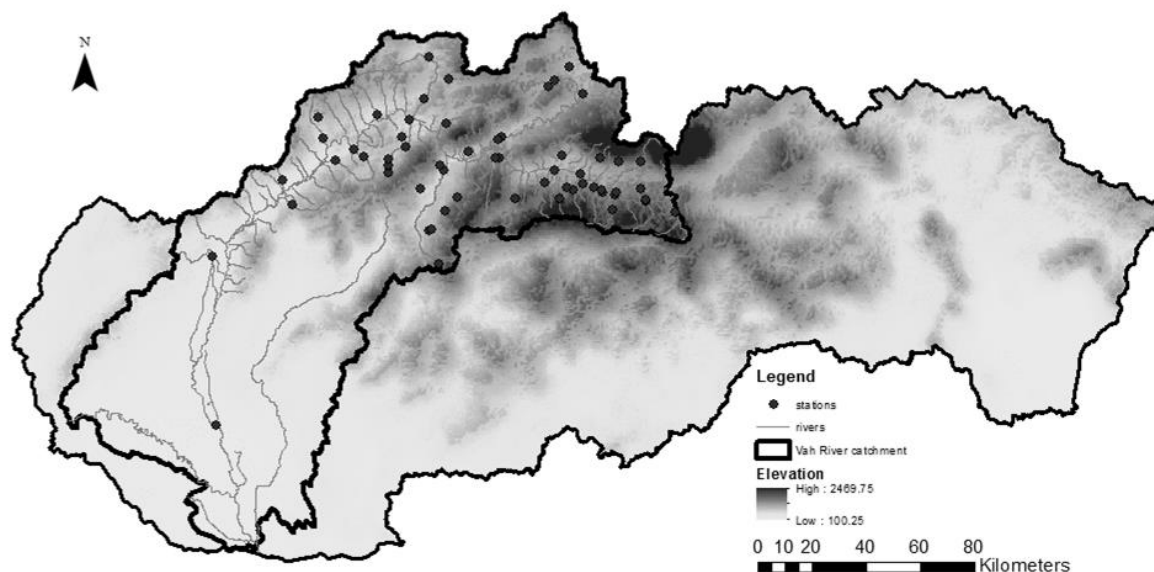


Figure 1. Location of the gauging stations in the Vah River basin, Slovak Republic.

4 RESULTS AND DISCUSSION

The homogeneity was tested on all 59 stations by the SNHT method for a single shift using AnClim software (Stepanek. 2007); 18 stations were found not to be homogeneous at a 5% level of significance (*Figure 2*). *Table 2* gives an insight when the critical values of SNHT were exceeded. It is possible to re-evaluate homogeneity after shortening the time series in 7 cases (5330, 5340, 5350, 5740, 5810, 5880 and 6150). After removing the extreme floods, all of the shortened time series were found to be homogenous at a 5% level of significance. Calculations were further performed with all 59 stations, and the final results were evaluated with an emphasis on the homogeneous stations.

Table 1. List of selected gauging stations in the Vah River basin

Station number	Name of the station	Catchment	Starting year of observations	Station number	Name of the station	Catchment	Starting year of observations
5300	Liptovská Teplička	Čierny Váh	1967	5890	Turany	Čiernik	1970
5310	Čierny Váh	Ipolitica	1961	5930	Turček	Turiec	1967
5311	Čierny Váh	Čierny Váh	1921	5970	Turčianske Teplice	Teplica	1963
5330	Východná	Biely Váh	1923	5980	Háj	Somolan	1969
5336	Malužiná	Boca	1970	6030	Brčna	Sloviansky P.	1969
5340	Kráľova Lehota	Boca	1931	6070	Blatnica	Gaderský P.	1969
5350	Kráľova Lehota	Hybica	1965	6110	Necpaly	Necpalský P.	1970
5370	Liptovský Hrádok	Váh	1951	6130	Martin	Turiec	1937
5400	Podbanské	Belá	1928	6140	Martin	Pivovarský P.	1969
5460	Račková Dolina	Račkový P.	1963	6150	Stráža	Varínka	1957
5480	Liptovský Hrádok	Belá	1965	6190	Zborov N/Bystricou	Bystrica	1949
5520	Liptovský Ján	Štiavnica	1963	6200	Kysucké Nové Mesto	Kysuca	1931
5530	Žiarska Dolina	Smrečianka	1963	6230	Rajecká Lesná	Lesňanka	1968
5540	Iľanovo	Iľanovianka	1969	6240	Šuja	Rajčianka	1968
5550	Liptovský Mikuláš	Váh	1932	6260	Rajec	Čierňanka	1968
5590	Demänová	Demänovka	1969	6290	Rajecke Teplice	Kunedradsky P.	1969
5650	Prosiek	Prosiečanka	1969	6300	Poluvsie	Rajčianka	1930
5660	Horáreň Hluché	Paludžanka	1970	6330	Lietava, Majer	Lietavka	1969
5680	Liptovský Sv. Križ	Paludžanka	1969	6340	Závodie	Rajčianka	1967
5720	Liptovské Vlachy	Kľačianka	1962	6360	Bytča	Petrovička	1961
5730	Partizánska Ľupča	Ľupčianka	1961	6370	Prečín	Domanižanka	1969
5740	Podsúchá	Revúca	1929	6380	Považská Bystrica	Domanižanka	1961
5780	Hubová	Váh	1921	6390	Vydrná	Petrinovec	1961
5790	Ľubochňa	Ľubochňianka	1959	6400	Dohňany	Biela Voda	1961
5800	Lokca	Biela Orava	1951	6420	Visolaje	Pružinka	1961
5810	Oravská Jasenica	Veselianka	1951	6450	Horné Srnie	Vlára	1961
5820	Zubrohlava	Polhoranka	1951	6460	Trenčianske Teplice	Teplička	1962
5840	Trstená	Oravica	1961	6470	Čachtice	Jablonka	1961
5870	Párnica	Zázrivka	1963	6480	Šaľa	Váh	1901
5880	Dierová	Orava	1931				

Table 2. Non- homogeneous stations at a 95% level of significance according to the SNHT test (*To* is the highest computed value of SNHT test statistics for the station; homogeneous stations after the removal of the extreme floods are marked in bold)

Station	Start year of observation	Statistic <i>To</i>	Critical values (Khaliq and Ouarda, 2007)	Critical value exceeded (Years)
5330	1923	14.272	9.047	1940–1957
5340	1931	9.303	8.951	1931
5350	1965	9.015	8.331	1965
5520	1963	8.711	8.382	1985–87
5650	1969	16.409	8.214	2009
5720	1962	17.566	8.382	1972–1984
5740	1929	15.753	8.976	1938–1963
5780	1921	19.802	9.067	1958–1995
5810	1951	9.079	8.647	1960
5840	1961	21.673	8.432	1999–2008
5870	1963	10.691	8.382	1993–1995
5880	1931	16.197	8.951	1940–1967
5890	1970	10.887	8.151	1979–1984
5970	1963	10.479	8.382	2009
6150	1957	11.616	8.524	1958, 1960
6360	1961	21.434	8.432	1995–2007
6390	1961	10.089	8.432	1973
6470	1961	15.362	8.432	2000–2005

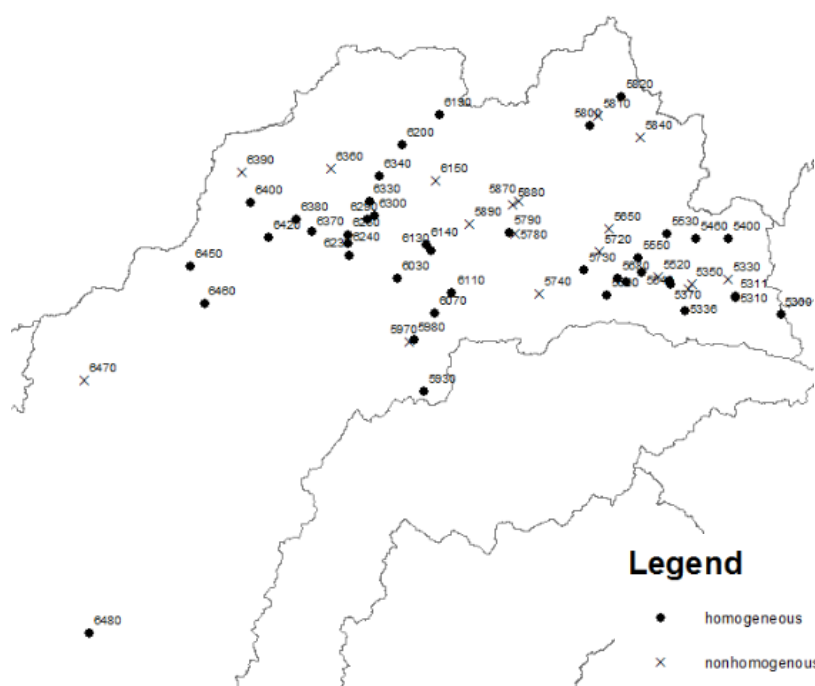


Figure 2. Map with locations and station number of homogeneous and nonhomogeneous stations at a 95% level of significance in the Vah River basin

For each of the 59 stations, the positive or negative direction of the trend was calculated by Sen's slope. The trend detected was positive in 27 cases and negative in 32 cases.

The MK and HR tests were applied to the discharge series in the Vah River catchment to assess the significance of the trend for different observation lengths: 40 years from 1970 to 2010; 50 years from 1960 to 2010; 60 years from 1950 to 2010; and the whole period of time observed at all the stations (40 years was the shortest and 109 years was the longest period). In the case of the autocorrelation in the time series, the test results of the MK and HR tests differ; therefore, there is a need to use the corrected HR test. The results were evaluated at the significance levels of 5, 10 and 20% (Table 3).

Table 3. Number of catchments at the levels of significance of 5, 10 and 20% by the MK and HR tests at different lengths of the observations

	Number of gauging stations		59		20		14		59	
	Time period (years)		40		50		60		40–109	
	Trend test		MK	HR	MK	HR	MK	HR	MK	HR
Significance level (number of stations)	5%		8	12	3	3	3	2	16	15
	10%		17	16	4	3	3	3	22	19
	20%		24	23	5	5	4	4	25	24

The null hypothesis (no trend in the time series) could not be rejected at the 20% significance level in 24 cases for the MK and 23 cases for the HR tests in the 40-year-long time period, in 5 cases for both the MK and HR in the 50-year-long time period, in 4 cases for both the MK and HR in the 60-year-long time period; and in 25 cases for the MK and in 24 cases for the HR for the whole time series. At the 10% level of significance, a trend was observed in 17 cases for the MK test and 16 for the HR test in the 40 year-long-period, 4 cases for the MK and 3 cases for the HR in the 50-year-long period, 3 cases for both the MK and HR during the 60-year-long-period; and in 22 cases for the MK and in 19 cases for the HR for the whole available time series. A trend at the 5% significance level was found in 8 cases for the MK and in 12 cases for the HR tests in the 40-year-long time period, in 3 cases for both the MK and HR in the 50-year-long time period, in 3 cases for the MK and in 2 cases for the HR in the 60-year-long time period, and in 16 cases for the MK and in 15 cases for the HR for the whole available time series.

Due to the autocorrelation present in the time series, the results for the MK trend test and HR test differ; therefore, the HR results were chosen for further analysis. The results of the HR trend test are presented in Figure 3, which describes the spatial distribution of rising or decreasing trends detected with significance at the 5%, 10% and 20% levels. The results of the 40 years of observations and the whole observed time period suggest the centralisation of a significant rising trend in the upper parts of the catchment and a decreasing trend in the lower parts of the upper Vah River basin. For the length of 50 years, the number of stations decreased to 20, and a significant trend was found in 5 stations, with a centralised rising trend present in the upper parts of the Vah River catchment. Sixty years of observations were available for 14 stations with a statistically significant trend in 4 stations with no clear spatial pattern.

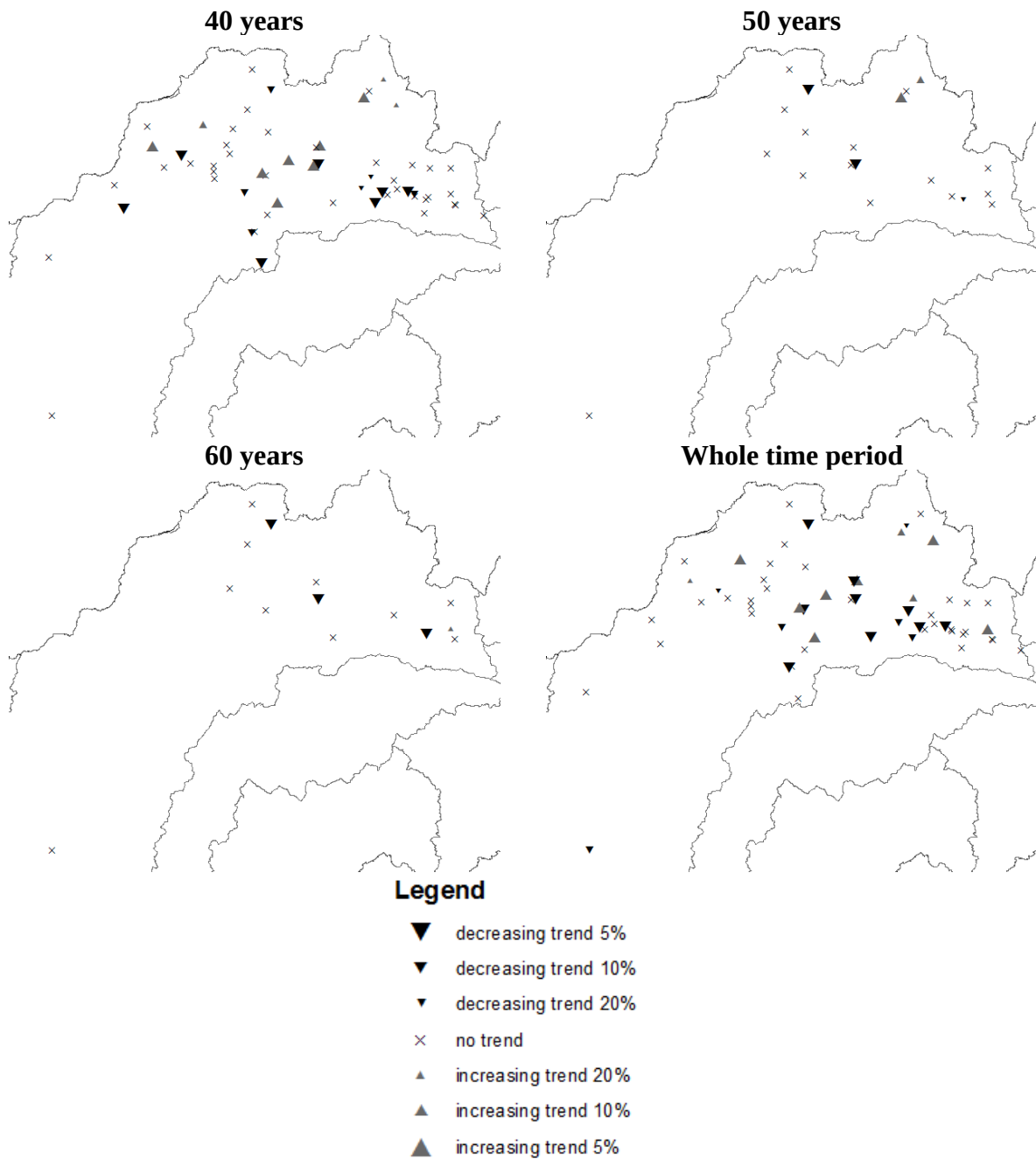


Figure 3. The results of the testing at the 5-, 10- and 20-% significance level

Subsequently, we took a closer look at 13 stations with observation periods longer than 60 years (*Table 3*). In the last column of *Table 4*, it can be seen that in stations with lengths of observations longer than 60 years, a statistically significant decreasing trend was found (Podsuchá, Hubová, Dierová, Martin, Zborov nad Bystricou and Šaľa); three of those time series (Podsuchá, Hubová and Dierová) were found to be non homogeneous by the SNHT test. A statistically significant rising trend was found at the Východná station, no trend was detected at the rest of the stations.

Table 4. Results of the significance analysis for catchments with 60 or more years of observations (the p-value is displayed in %); bold – statistically significant values for a rising trend, bold-italic – statistically significant values for a decreasing trend

Station	Name	Homogeneity	Years of observation	Sen's slope	P-value (%)			
					40y	50y	60y	whole
5311	Čierny Váh	Yes	89	increasing	69.42	70.87	39.38	52.15
5330	Východná	No	87	increasing	93.73	38.04	15.23	0
5340	Kráľova Lehota	No	79	decreasing	24.73	19.16	2.67	30.09
5400	Podbanské	Yes	82	decreasing	81.35	94.17	65.41	66.24
5550	Liptovský Mikuláš	Yes	62	decreasing	26.09	58.9	65.57	36.57
5740	Podsúchá	No	81	decreasing	46.53	40.28	49.36	0.77
5780	Hubová	No	89	decreasing	0.53	0.3	0.03	0
5880	Dierová	No	79	decreasing	87.5	66.92	25.79	0
6130	Martin	Yes	73	decreasing	86.62	53.7	62.02	3.53
6190	Zborov nad Bystricou	Yes	61	decreasing	6.74	0.17	7.42	7.15
6200	Kysucké Nové Mesto	Yes	79	decreasing	94.26	27.58	85.26	47.61
6300	Poluvšie	Yes	80	increasing	62.11	25.89	96.24	98.39
6480	Šaľa	Yes	109	decreasing	62.91	32.97	27.07	6.48

5 CONCLUSIONS

The paper was focused on an analysis of changes in annual maximum discharges in the Vah River basin by the use of trend significance analysis methods. The quality of the data set was tested by the Alexandersson SNHT test. The MK and HR trend tests were applied to different observation lengths – 40, 50, 60 and more than 60-year-long time series obtained from 59 gauging stations in the Vah River catchment.

A more detailed analysis of 13 stations with the longest periods of observations revealed that with a prolonged length of observation, the possibility of detecting a statistically significant trend increases. The short length of the time series (in some cases, 40 years) may have influenced the possibility of detecting a significant trend in the Vah River catchment, in that any prolongation of a time series observed can significantly influence the detection of a significant trend at the 5% significance level (Diermanse et al. 2010). When we also took into consideration the homogeneity analysis results of the SNHT method, a statistically significant decreasing trend was present at the Dierová, Martin, Zborov nad Bystricou and Šaľa stations.

Finally, we can conclude that a significant rising trend was detected in the upper part of the catchment, mainly in the east Tatra Mountain region and a decreasing trend in the lower part of the upper Vah River basin. These results can help when mapping flood risk areas and developing river basin management plans in the Vah River basin.

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Changes in Snow Storage in the Upper Hron River Basin (Slovakia)

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Abstract - An evaluation of changes in the snow cover in mountainous basins in Slovakia and a validation of MODIS satellite images are provided in this paper. An analysis of the changes in snow cover was given by evaluating changes in the snow depth, the duration of the snow cover, and the simulated snow water equivalent in a daily time step using a conceptual hydrological rainfall-runoff model with lumped parameters. These values were compared with the available measured data at climate stations. The changes in the snow cover and the simulated snow water equivalent were estimated by trend analysis; its significance was tested using the Mann-Kendall test. Also, the satellite images were compared with the available measured data. The results show a decrease in snow depth and in snow water equivalent from 1961–2010 in all months of the winter season, and significant decreasing trends were indicated in the months of December, January and February.

snow depth / snow water equivalent / trend analysis / MODIS satellite images

Kivonat – A tározott hókészlet változásai a Garam (Hron) felső vízgyűjtőjében, Szlovákiában.

A tanulmány Szlovákia hegyvidéki vízgyűjtőiben a hóborítottság változását értékeli, és bemutatja a MODIS műhold képek értékelését is ehhez kapcsolódóan. A hóborítottság változásának analízise magában foglalta a hótakaró vastagságának, a hóborítottság időtartamának és a szimulált hó-víz egyenértéknek a napi időlépcsőben történő értékelését, amelyhez a szerzők egy koncentrált paraméterű csapadék-lefolyás modellt használtak fel. Az modellezés során kapott értékeket a meteorológiai állomásokon rendelkezésre álló terepi mérési adatokkal hasonlították össze. A hóborítottság és a szimulált hó-víz egyenérték változását trend analízis segítségével becsülték, a megbízhatóság értékelésére Mann-Kendall tesztet használtak. A távérzékelési alapú adatokat a terepi mérési adatokkal is összehasonlították. Az eredmények alapján valószínűsíthető a hótakaró vastagságának és a hó-víz egyenértéknek általában a csökkenése a vizsgált 1961–2010-es időszakban minden egyes téli (téli félév) hónapra vonatkozóan, avval a kiegészítéssel, hogy a csökkenési tendencia szignifikáns a december, január és február hónapok esetében.

hótakaró vastagság / hó-víz egyenérték / trend elemzés / MODIS képek

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1 INTRODUCTION

Snow cover is a very important part of a hydrological balance. The most important value of snow is the snow water equivalent (SWE). The snow water equivalent is the value of the amount of water in snow. Knowledge of the temporal and spatial variability of SWE is significant for the correct assessment and prediction of runoff from snow melting processes.

Snow data is rarely available in Slovakia from the second half of the 19th century, but it is regularly available from the second half of the 20th century from standard rain gauge stations. The measured data include the height of the snow cover, the date of the first and last days with snow cover, the duration of the snow cover, the snow water equivalent, etc.

Several authors investigated the spatial and temporal changes in the snow depths, and the density of the snow cover, the spatial and temporal changes in snow water equivalent, the impact of vegetation during the snow melt, and the impact of vegetation and catchment characteristic on hydrological balance (Hood – Hayashi 2010, Kuchment et al. 2010, Artan et al. 2013), and also several authors in Slovakia (Holko 2000, Holko et al. 2011, Pekárová et al. 2009, Gaál et al. 2012). Another authors in Slovakia have used rainfall-runoff models for modelling extreme runoff from snow melt in river basins (Holko 2000). They used models such as the UEB EHZ model (Holko et al. 2005), the WaSiM-ETH model, or the HBV model with semi-distributed parameters (Parajka 2001, Pekárová – Miklánek 2006, Halmová et al. 2006, Lapin et al. 2007, Danko et al. 2010).

Snow is a main element of stream flow in alpine basins, and quantifying snow depth and its distribution is important for hydrological modelling. In this paper we analysed the changes in snow storage during recent decades in alpine basin, the upper Hron River basin. The analysis was performing by assessing changes in snow duration and changes in the simulated snow water equivalent by hydrological modelling using the rainfall-runoff model Hron. The significance of the changes was evaluated by a trend analysis.

In the individual chapters of this paper we describe the input data, the concept and parameters of the rainfall-runoff model Hron, the methodology for assessing the duration of the snow cover measured in selected climate stations, a simulation of the snow water, the results of the assessment of any changes in the snow duration and simulated SWE for the period 1961–2010, and the identification of any trends in snow duration and the SWE for the months from November to April.

In 3.3. chapter we describe another source of snow data, i.e., the satellite images of the Moderate Resolution Imaging Spectroradiometer (MODIS) snow product. These data were evaluated and validated by measured data from 2000–2010 in five climate stations. The overall degree of agreement and the misclassifications were evaluated and filtered for increasing the accuracy of the satellite images.

2 INPUT DATA

The river basin analysed in this paper is the upper Hron River basin with its outlet at Banská Bystrica. The Hron River is the second longest river in Slovakia; its length is 298 km. It has a snow-rain runoff regime; the highest mean monthly flows occur in April and the lowest mean monthly flows in January and February. The catchment belongs to a cold and wet climate region; the highest measured mean daily air temperature is 29°C; the mean annual air temperature is between 4 and 5°C; the highest average monthly air temperature is between 14 and 16°C; and the lowest average monthly air temperature is between –4 and –6°C (Pekárová – Szolgay 2005).

The data representing the snow cover included measurement of the daily data of the snow depths and the weekly data of the snow water equivalent at 5 climate stations on the Hron river basin from the period 1961–2010. The input data for modelling the basin's snow water equivalent by the rainfall-runoff model were daily rainfall data from 23 rain gauge stations, the mean daily values of the air temperature from 6 climate stations, and the mean daily discharges in the profile of Banská Bystrica for the period 1961–2010. The basin's daily rainfall was processed by the interpolation method of inverse distance weighting; the basin's average air temperature values were calculated by linear regression between the stations' mean daily air temperatures and the altitudes of the climate stations. The daily evapotranspiration values were calculated by the Blaney-Criddle method (Parajka et al. 2003). The calculations were based on the basin's average daily air temperature and the sunshine index of the river basin.

Satellite images of the Moderate Resolution Imaging Spectroradiometer (MODIS) snow product were available from the official website of the National Snow and Ice Data Centre (<http://nsidc.org/>) in a daily time step from 2000–2010. These data were obtained from the MODIS sensor on the Aqua and Terra satellites of NASA's Earth Observing System (EOS). The spatial resolution of the data was 500 m.

The list of climate stations with the available measured data of the snow depths and snow water equivalent is in Table 1, and their location is in Figure 1.

Table 1. List of climate stations with the available measured data of the snow depth and snow water equivalent

Station	Chopok	Lom nad Rimavicou	Telgárt	Brezno	Banská Bystrica
Altitude [m asl]	2008	1018	901	487	427

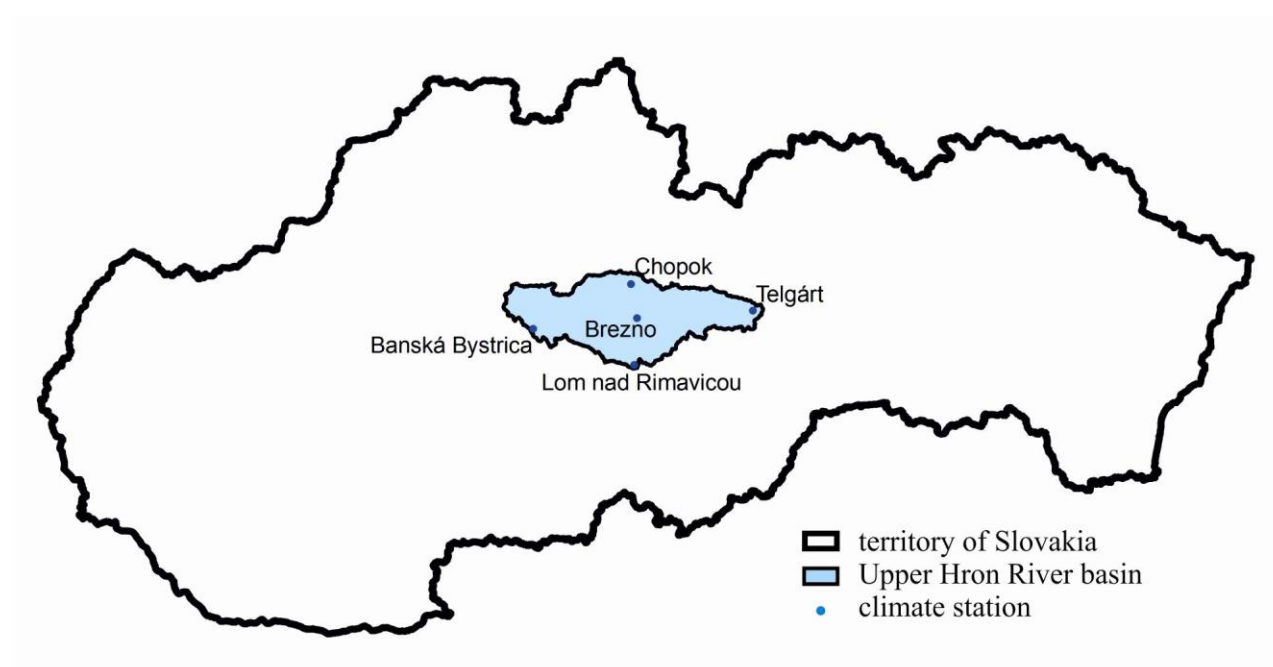


Figure 1. Location of climate stations with the available measured data of the snow depth and snow water equivalent

3 METHODOLOGY

3.1 Changes in duration of snow

The changes in snow cover from 1961–2010 were estimated by an analysis of the measured snow depth and its duration in the individual years and climate stations. In every year we totaled the number of days with a measurable snow depth. The data with values lower than 0.5 cm of snow depth we considered to be statistically irrelevant; therefore, only days with values higher than 0.5 cm of snow depth were taken into account.

The significance of the trend at the 95% level of significance was tested using the Mann-Kendall test. The Mann-Kendall test, which is one of the many methods used to detect trends, is the most widely used test. It is a non-parametric test which has the ability to deal with non-normalities, e.g., missing values. Its disadvantages include results that are not as strong as parametric tests.

3.2 Changes in snow water equivalent

The snow water equivalent was simulated by a rainfall-runoff model with lumped parameters. Its changes were assessed by a trend analysis, and the significance of the trends was tested using the Mann-Kendall test.

3.2.1 The rainfall-runoff model Hron

The model Hron is a rainfall-runoff model developed at the Department of Land and Water Resources Management of the Faculty of Civil Engineering of Slovak University of Technology in Bratislava (Kubeš 2007, Kubeš – Hlavčová 2002). The structure of this model is derived from the concept of the HBV model (Bergström 1976, 1992). This is a conceptual model with lumped parameters, which divides a river basin into 2 linear or nonlinear reservoirs according to the scheme in Figure 2.

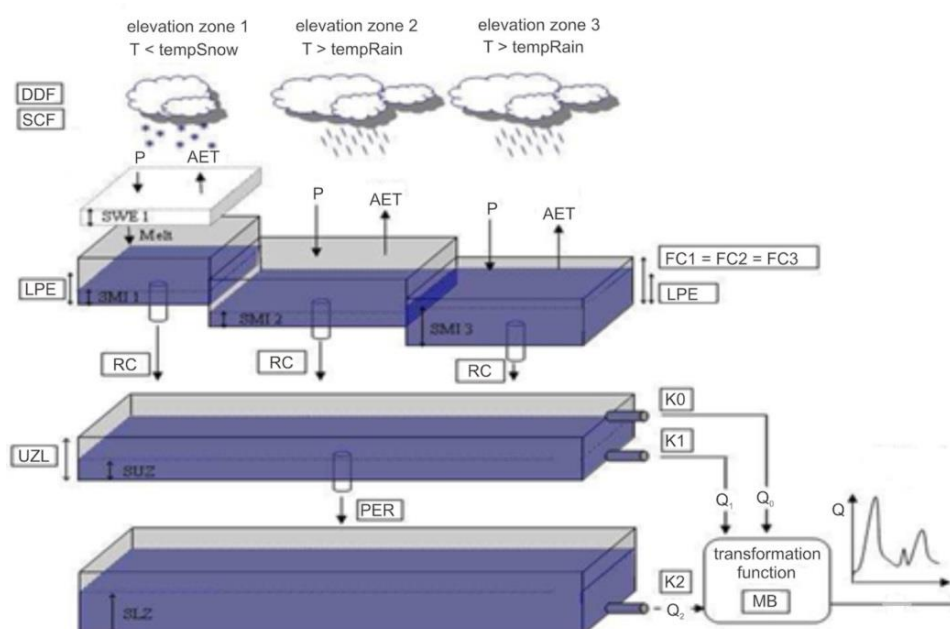


Figure 2. Scheme of the rainfall-runoff model Hron (Valent et al. 2011)

The model works in an hourly or daily time step and has three sub-models. The first sub-model is a snow sub-model for the simulation of snow accumulation and melting. The second, a soil sub-model, simulates the amount of water in soil and the actual evapotranspiration. The third, a runoff sub-model, simulates the transformation of the runoff in a river basin, respectively, the transformation of the flow in a river bed.

The manual or automatic calibration of model parameters is based on genetic algorithms or harmonic searching as well as on several objective functions for assessments of the reliability of the model's calibration. The actual version of the model Hron is programmatically processed in Matlab (Valent et al. 2011).

The calibrated model parameters are:

- FC – field capacity [mm],
- RC – recharge coefficient [–],
- UZL – upper zone limit [mm],
- tempRain – threshold temperature, above which all precipitation is liquid [°C],
- tempMelt – threshold temperature, determining the snow melting process [°C],
- tempSnow – threshold temperature, under which all the precipitation is solid [°C].
- DDF – degree-day factor [mm/°C/day],
- PER – percolation [mm],
- LPE – limit of potential evapotranspiration [–],
- K0 – parameter influencing the surface (Q_0) flow [–],
- K1 – parameter influencing the subsurface (Q_1) flow [–],
- K2 – parameter influencing the base (Q_2) flow [–],
- SCF – snow correction factor,
- MB – parameter determining the amount of days into which the total runoff is divided using a triangular weighted function.

The simulated basin states in every time unit are characterized by the state variables of the model: the values of the soil moisture SM [mm], the water level in the upper basin SUZ [mm], the water level in the lower basin SLZ [mm], and the snow water equivalent SWE [mm].

3.2.2 Calibration of model parameters

The aim of modelling the hydrological processes by the rainfall-runoff model Hron was to obtain the simulated daily values of the snow water equivalent. The reliability of the calibration of the model parameters using genetic algorithms was assessed by 1) compliance of the simulated and measured mean daily discharges in the basin outlet by the Nash-Sutcliffe coefficient; 2) validation with other samples of data by the differential split-sample test; and 3) comparison of the simulated and measured values of SWE.

In the process of calibrating the model parameters, the whole period of 1961–2010 was divided into five shorter periods, i.e., decades (starting in June 1961), for increasing the reliability of the simulated SWE in each decade. The parameters of the model were calibrated individually for each decade, and other decades were used for the validation of the model's parameters.

It was assumed that the SWE values obtained by the simulation with the parameters calibrated for the decades are more reliable than the values obtained by the simulation with the parameters calibrated for the whole 50 years. Therefore, the representative series of the snow water equivalent (the most reliable) was created by a combination of the simulated SWE from the decades with the calibrated parameters of each decade. The other series were created by a simulation of the period 1961–2010 with the parameters calibrated step by step from the first, second, third, fourth, and fifth decades.

The next step was the validation of the simulated SWE with the measured data. We compared the simulated daily values from the representative SWE series, which represents the basin's average data, with the measured basin's SWE averages. The basin's SWE averages were calculated from the measured SWE values at the climate stations by linear regression with the altitudes of the climate stations.

Finally, the changes in the simulated snow water equivalents in the basin were assessed by the trend analysis, and the significance of the trends was tested using the Mann-Kendall test.

3.3 Validation of the MODIS satellite data

The accuracy of the MODIS data was compared with the data measured from the area studied (Hall – Riggs 2007, Mauer et al. 2003). Two types of errors were evaluated in this validation. The sum of the misclassification of snow as land was divided by the total number of cloud-free days in percentages – the underestimation error; and the sum of the misclassification of land as snow was divided by the total number of cloud-free days in percentages – the overestimation error. The sum of correctly classified days (snow, snow and no snow, no snow) divided by the total number of cloud-free days in percentages represents the overall degree of agreement (Parajka – Blöschl 2006, 2008a, b, Parajka et al. 2012).

Subsequently, the temporal filtering of the MODIS images was used to increase the accuracy of the images. The pixels classified as clouds were replaced by the values of the same cells of the previous day to decrease these pixels. So, a pixel classified as a cloud was replaced by a pixel value if the pixel of the previous day was snow or land. Various time steps were used for the temporal filtering. Next, the MODIS data were compared with the measured data. The overall degree of agreement, underestimation and overestimation were calculated for all the decades at each station in all the months of the winter season.

4 RESULTS

4.1 Duration of snow cover

A graphic illustration of the changes in snow duration for the period 1961–2010 at 5 climate stations on the Hron River basin is shown in *Figures 3–7*. The graphs demonstrate the decreasing trend in the duration of the snow cover at 4 stations and the increasing trend at the Banská Bystrica climate station. The significance of the increasing and decreasing trends at the 95% level of significance was tested using the Mann-Kendall test.

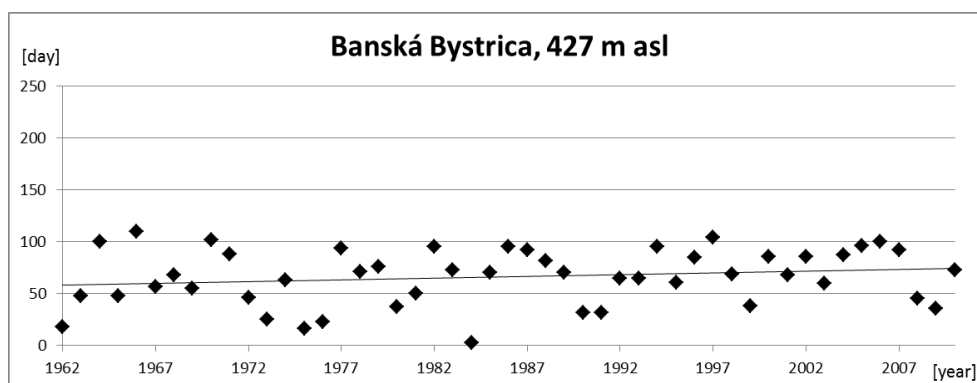


Figure 3. The duration of the snow cover at the Banská Bystrica climate station

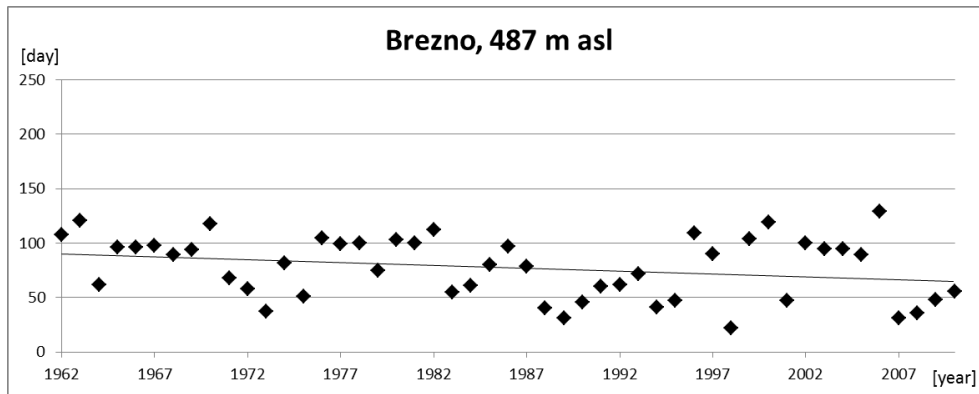


Figure 4. The duration of the snow cover at the Brezno climate station

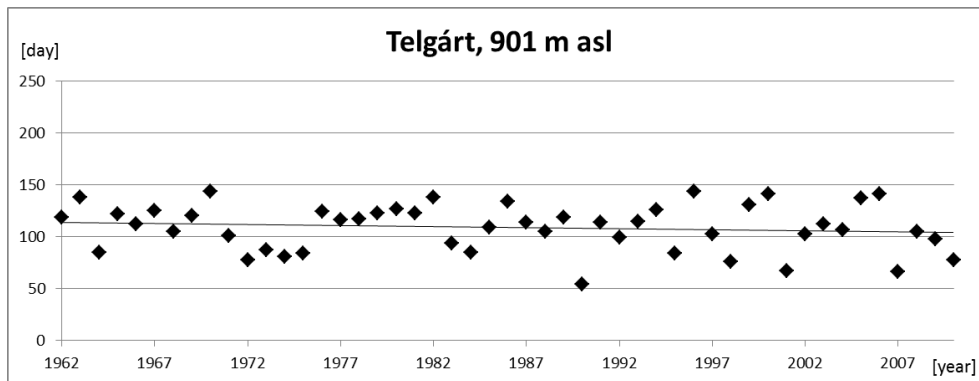


Figure 5. The duration of the snow cover at the Telgárt climate station

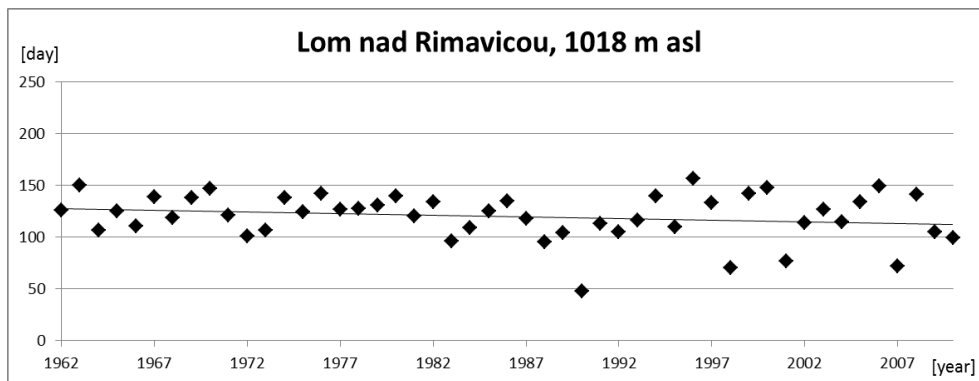


Figure 6. The duration of the snow cover at the Lom nad Rimavicou climate station

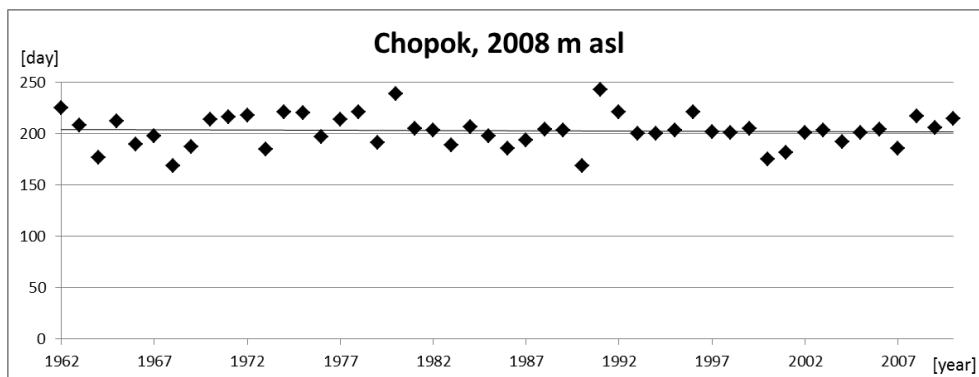


Figure 7. The duration of the snow cover at the Chopok climate station

We can see a decreasing trend in the duration of the days with snow cover, but no significantly trend were detected using the Mann-Kendall test.

4.2 Simulation of snow water equivalent

4.2.1 Calibration and validation of model parameters

It was mentioned that the parameters of the model were calibrated individually for each decade, and other decades were used for the validation of the model's parameters. The values achieved of the Nash-Sutcliffe coefficient are listed in Table 2.

Table 2. Values of the Nash-Sutcliffe coefficient for the calibration and validation periods (grey – calibration, white – validation)

↑ Validation ↓	1961–1971	1971–1981	1981–1991	1991–2000	2000–2010
1961–1971	0.7987	0.689	0.7301	0.7187	0.7162
1971–1981	0.7124	0.8041	0.7466	0.7379	0.7608
1981–1991	0.7175	0.7499	0.7341	0.7423	0.6546
1991–2000	0.7386	0.784	0.804	0.7911	0.6505
2000–2010	0.6701	0.7031	0.6889	0.6506	0.7595

A comparison of the simulated mean monthly SWE for the months of the winter season and the period 1961–2010 is shown in Table 3 (Juričková et al. 2013).

Table 3. Mean monthly basin averages of SWE for the period 1961 –2010

	Nov [mm]	Dec [mm]	Jan [mm]	Feb [mm]	March [mm]	April [mm]
Representative series of SWE	3.79	25.46	56.53	79.67	71.41	16.18
SWE simulated with parameters from period 1961–1971	3.67	24.58	54.46	75.82	67.14	14.34
SWE simulated with parameters from period 1971–1981	4.02	23.57	49.51	70.00	61.18	11.81
SWE simulated with parameters from period 1981–1991	3.94	26.36	58.52	82.97	75.82	18.63
SWE simulated with parameters from period 1991–2000	3.58	23.36	51.58	72.63	65.63	15.50
SWE simulated with parameters from period 2000–2010	4.06	24.09	52.04	69.98	59.58	10.14

The next step was the validation of the simulated SWE with the measured data. From the comparison of the simulated daily values from the representative SWE series with the measured basin's SWE averages, we can see a satisfactory compliance between the simulated and measured daily SWE values. Some differences could be caused by a problematic determination of the basin's average value of the measured SWE, which was caused by the missing data in some climate stations. As illustration, a comparison of the measured and simulated basin's SWE for the period's 1981–1990 (Figure 8) and 1991–2000 (Figure 9) are presented here.

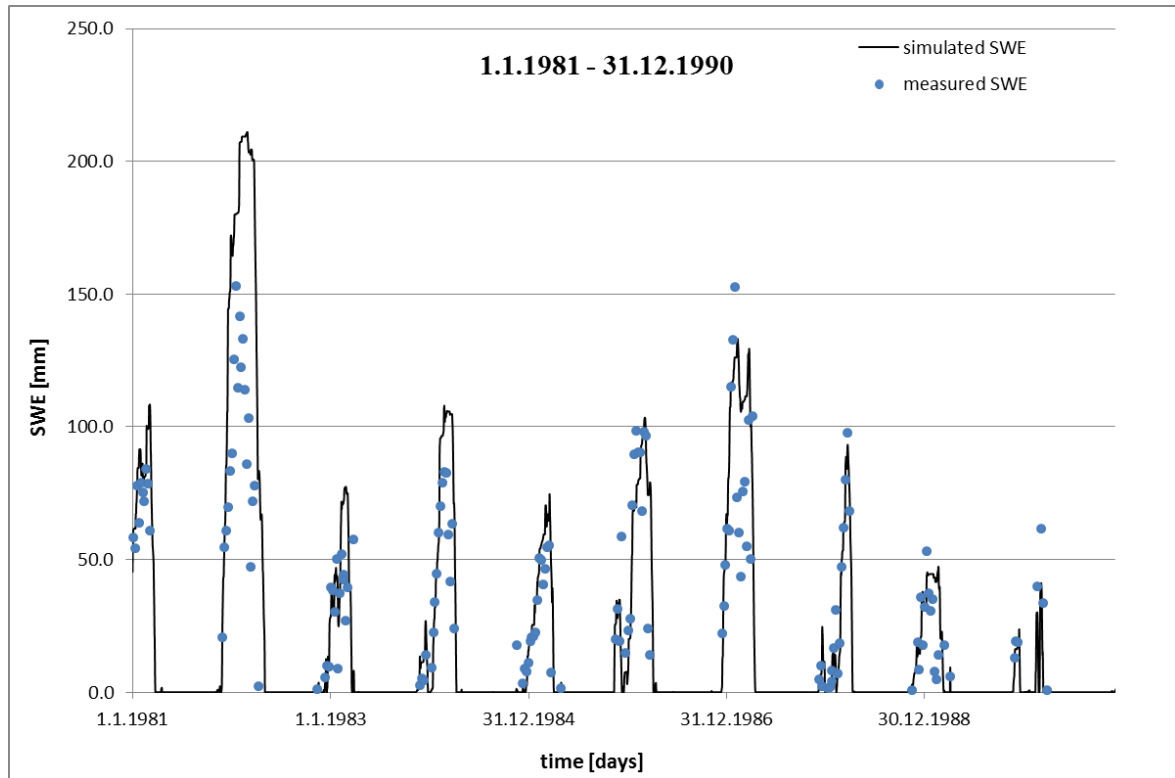


Figure 8. Comparison of the measured and simulated basin's SWE for the period 1981–1990

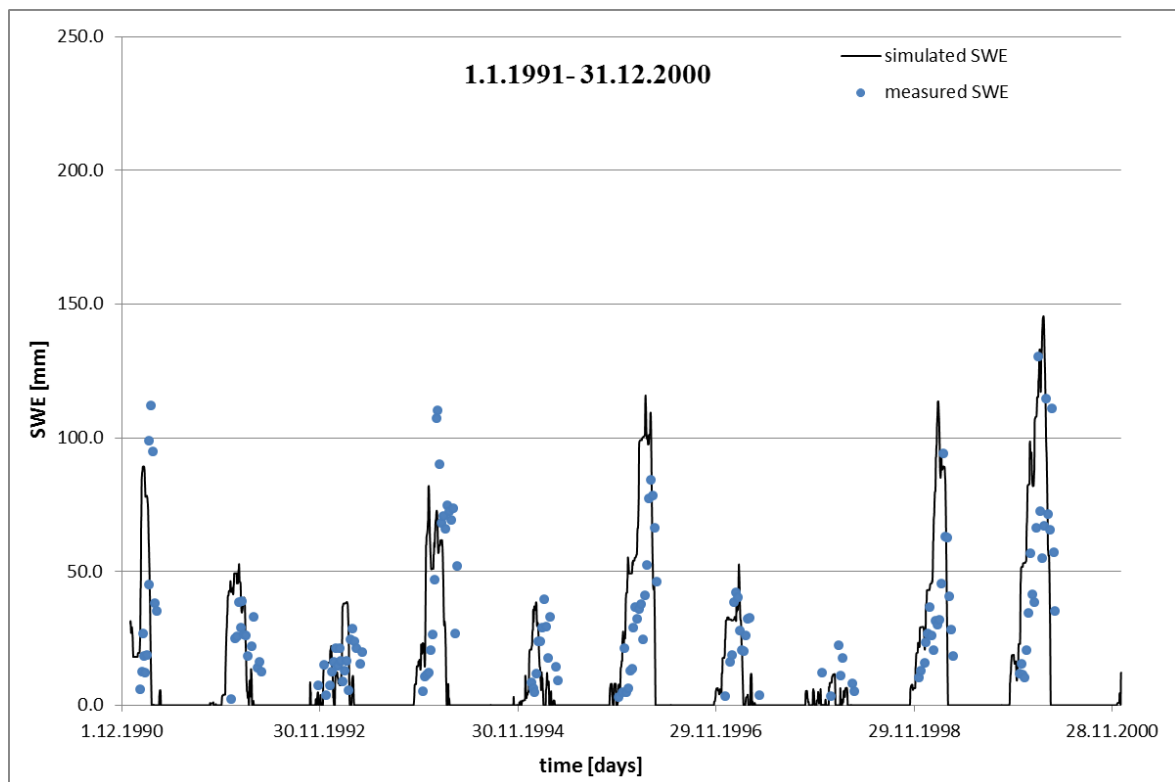


Figure 9. Comparison of the measured and simulated basin's SWE for the period 1991–2000

The changes in the simulated snow water equivalents in the basin were assessed by the trend analysis, and the significance of the trends was tested using the Mann-Kendall test (*Table 4*). From the table we can see a statistically confirmed significant trend at the 95% level of significance in some months. From the results it is possible to indicate a decrease in the snow water equivalent on the upper Hron River basin in the period of 1961–2010 in all the months of the winter season, and significantly decreasing trends were indicated in the months of December, January and February.

Table 4. Significance of decreasing trends of the simulated basin's SWE in the individual months

Month	Significant trend (level of 95% significance)
November	No
December	Yes
January	Yes
February	Yes
March	No
April	No

4.3 MODIS satellite images

In this part of the study the validation of the MODIS data by comparing it with the measured data from the study area was provided. Next, the temporal filtering of the MODIS images was applied to increase the accuracy of the images. Finally, the MODIS data were compared with the measured data.

4.3.1 Validation of the MODIS satellite images

The monthly values of the overall degree of agreement of the MODIS satellite images are shown in *Table 5*, and the yearly values of the accuracy index of the overall agreement and misclassification of the original MODIS data are shown in *Table 6*.

Table 5. The monthly values of the overall degree of agreement of the original MODIS satellite images

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
November	95.455	90.909	86.49	92.929	41.250
December	94.681	87.273	93.00	81.746	65.546
January	92.593	89.655	97.98	92.000	93.976
February	90.000	86.598	80.52	89.109	95.946
March	85.185	79.661	63.73	86.842	94.318
April	99.432	99.375	77.12	90.977	23.009

Table 6. Yearly values of the accuracy index of the overall degree of agreement and misclassification of the original MODIS data

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
Overall degree of agreement	91.802	88.822	79.836	89.732	76.812
Underestimation	0.119	0.577	1.00	2.589	1.072
Overestimation	2.380	3.926	7.31	3.070	28.637

Subsequently, the temporal filtering of the MODIS images was used to increase the accuracy of the images. Next, the MODIS data were compared with the measured data. The overall degree of agreement, underestimation and overestimation were estimated for all the decades in each station in all the months of the winter season (Tables 7–12).

Table 7. The monthly values of the overall degree of agreement of the satellite images after temporal filtering (time step: 1 day)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
November	94.44	92.64	85.47	93.17	40.91
December	93.06	86.14	92.36	80.66	66.07
January	93.85	90.14	96.03	90.57	93.23
February	89.68	88.11	81.67	87.42	96.30
March	86.54	78.61	68.39	88.02	95.35
April	98.74	99.10	75.71	89.58	21.56

Table 8. Yearly values of the accuracy index of the overall degree of agreement and misclassification of the sensor after temporal filtering (time step: 1 day)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
Overall degree of agreement	92.20	88.99	80.45	88.90	76.61
Underestimation	0.13	0.57	1.27	2.65	1.24
Overestimation	2.71	4.21	7.44	3.49	28.96

Table 9. The monthly values of the overall degree of the agreement of satellite images after temporal filtering (time step: 2 days)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
November	93.12	93.20	83.18	90.73	40.00
December	90.06	83.90	90.55	81.48	66.67
January	88.62	87.29	95.74	88.78	92.73
February	89.24	88.07	83.44	88.20	96.38
March	86.91	79.05	69.39	87.08	95.65
April	98.53	98.43	76.96	88.39	21.89

Table 10. Yearly values of the accuracy index of the overall degree of agreement and misclassification of the sensor after temporal filtering (time step: 2 days)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
Overall degree of agreement	90.83	88.21	81.38	88.11	76.66
Underestimation	0.14	0.52	1.42	2.77	1.31
Overestimation	3.53	4.79	7.68	3.91	29.12

Table 11. The monthly values of the overall degree of the agreement of satellite images after temporal filtering (time step: 3 days)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
November	91.56	93.70	81.40	89.83	39.20
December	88.57	82.55	88.28	81.97	67.53
January	86.15	86.12	96.31	89.19	91.62
February	88.59	87.06	85.55	89.05	96.27
March	86.88	78.75	69.60	87.29	95.72
April	98.63	98.19	76.23	88.26	21.93

Table 12. Yearly values of the accuracy index of the overall degree of agreement and misclassification of the sensor after temporal filtering (time step: 3 days)

	Banská Bystrica (%)	Brezno (%)	Telgárt (%)	Lom nad Rimavicou (%)	Chopok (%)
Overall degree of agreement	90.06	87.53	81.92	88.45	76.39
Underestimation	0.16	0.51	1.54	2.90	1.49
Overestimation	4.10	5.24	7.99	3.90	29.22

The mean value of the overall degree of the agreement of the original satellite images is 85.4%; the overestimation is 9.1%; and the underestimation of the images is 1.1%. After the temporal filtering, these values were changed. Overall, the values of the overall degree of the agreement has not changed significantly, but the mean value of the underestimation was changed by 0.25%, and the mean value of the overestimation after the temporal filtering in the 1–3 day time step was changed by more than 1% – the misclassification of snow as land is increasing, but the misclassification of land as snow is approximately the same (Parajka – Blöschl 2008a, Marchane et al. 2014). In our future work, we expect higher values of the overall degree of the filtered satellite images by a combination of temporal and spatial filtering.

5 DISCUSSION AND CONCLUSIONS

Snow cover is a significant natural phenomenon; precipitation is accumulated during some months in the winter season and then is released in a very short time. This has quantitative and qualitative impacts on the water cycle.

The changes in the duration of the snow cover were evaluated in the period of the hydrological years of 1962–2010. This assessment was conducted using measured data from the five climate stations in the upper Hron River basin from different elevations. From the comparison, we can see a decreasing trend in the duration of the days with snow cover and, according to the Mann-Kendall statistical test.

We focused on an assessment of the changes in the snow water equivalent values in the upper Hron River basin in the period of 1961–2010. In the catchment we simulated the daily values of the SWE by the rainfall-runoff model Hron with lumped parameters. The period of 1961–2010 was divided into five decades; they were particularly calibrated, and the other years were used for the validation of the parameters of the model Hron. In this way we wanted to review the impact of the changed parameters of the simulated values of the SWE.

From the Nash-Sutcliffe (NS) values we can see higher values of NS in every calibrated decade than in the validated periods, except for the period of 1981–1990. No significant change of the model's parameters was detected over time. We assume that the state variables of the model obtained by simulating a shorter period are more reliable than the simulated values obtained with the simulated parameters calibrated for the entire period of 50 years.

From the comparison of the basic SWE statistics simulated from the whole period of 1961–2010 with the different sets of model parameters calibrated, we can state that the different sets of model parameters had an effect on the simulated SWE values in the individual months. Therefore, for the final analysis we selected the simulated SWE achieved from the simulations of the individual decades with each of their own calibrated parameters. These values of the “representative” simulated SWE were also consistent with the measured basin's values, which were estimated from the available measured SWE data from the climate stations in the basin.

The changes in the representative simulated SWE were evaluated by the trend analysis in the individual months, and the statistical significance of the trends was assessed by the Mann-Kendall statistical test. From the results it is possible to demonstrate a decrease in the SWE on the upper Hron River basin in the period of 1961–2010 in all the months of the winter season, and significant decreasing trends were indicated in months of December, January and February.

Finally, we evaluated and validated the MODIS satellite images and evaluated the accuracy of the MODIS snow data. These data were compared with the measured data in the area of interest, and the index of the accuracy, the overall degree of the agreement, and the misclassifications of the sensor were determined. The mean value of the overall degree of agreement of the original satellite images for the winter seasons was 85.4%; the overestimation was 9.1%; and the underestimation of the images was 1.1%. After the temporal filtering, the misclassification of snow as land was increased, but the misclassification of land as snow was approximately the same.

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Alternative Approaches to a Calibration of Rainfall-Runoff Models for a Flood Frequency Analysis

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Abstract – One of the tools which are currently being used in flood frequency analysis (FFA) is rainfall-runoff (RR) modelling. Its use in FFA often confronts the problem of how to correctly calibrate RR models to extreme flows. Since FFA only deals with extreme flows, traditional calibration techniques using simple objective functions such as the Nash-Sutcliffe model's efficiency criterion are not sufficient. In this paper we have focused on proposing alternative approaches for calibration techniques of RR models in order to enhance the description of extreme flows. We have selected the HBV type conceptual, lumped model HRON as an RR model. We have suggested two alternative calibration approaches: 1) the use of a new optimization function that compares only values higher than the 95th percentile of observed flows and 2) using two sets of parameters to separately simulate low and high flows. Each of these improvements has enhanced the simulation of extreme flows, which has been demonstrated in the empirical cumulative distribution function calculated for the simulated and observed annual maximum series of flows. The results of this paper show that improvement can be obtained by both approaches, which give good agreement between observed and simulated extreme flows, while preserving a good simulation of low and medium flows.

rainfall-runoff model / calibration / annual maximum series of flows / flood frequency analysis

Kivonat – Gyakoriság-tartóssági vizsgálatra használt csapadék lefolyási modellek kalibrációjának alternatív megközelítései. Az árhullámok gyakoriság-tartóssági vizsgálatára (FFA) a napjainkban használt eszközök egyike a csapadék-lefolyás (RR) modellezés. Ennek használata során gyakran kerülünk szembe avval a problémával, hogy hogyan tudjuk korrekt módon kalibrálni a RR modelleket az extrém vízhozamokra. Mivel az FFA csak az extrém vízhozamokra koncentrál az olyan egyszerű, objektív függvényekkel dolgozó, klasszikus kalibrációs módszerek, mint a Nash-Sutcliffe féle kritérium nem megfelelőek. Jelen tanulmány alternatív megközelítéseket javasol a RR modellek kalibrálására, abból a célból, hogy az extrém vízhozamok elemzését javítsa. A vizsgálatra a HBV típusú koncepcionális, koncentrált paraméterű HRON modellt, mint RR modellt választottuk ki. Két alternatív kalibrációs megközelítést javasoltunk: 1) új optimalizációs függvény használata, amely csak a vizsgált vízhozamok 95. percentilisének nagyobb értékeit hasonlítja össze és 2) két paraméter készlet használata külön a kis és a nagy vízhozamok szimulációjára. Mindkét új fejlesztési megközelítés javítja az extrém vízhozamok szimulációját, a fejlesztések hatását a szimulált és mért éves maximális vízhozam idősorok empirikus tartóssági görbéinek segítségével mutatjuk be. A tanulmány szerint mindkét megközelítés javulást eredményezhet, amely a vizsgált és szimulált extrém vízhozamok közötti jó egyezéssel igazolható, az alacsony és közepes vízhozamok tartományában való jó szimuláció megtartása mellett.

csapadék lefolyás modell / modellillesztés / évi maximális vízhozam idősorok/ gyakoriság-tartósság vizsgálat

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1 INTRODUCTION

In derived flood frequency analysis (FFA), rainfall-runoff (RR) models are commonly used to continually simulate runoff from a catchment. One of the strongest motivations for the use of RR models in FFA is that, together with stochastic rainfall models, they enable the easy simulation of arbitrarily long series of river flows containing unobserved combinations of extreme values. Such a long series of river flows can be subsequently used to extract various flood characteristics such as peak flow, flood volume or flood duration. One of the advantages of continuous simulation compared to event-based RR models is that these models can also simulate different variables representing the state of the catchment (e.g., soil moisture, evapotranspiration, the amount of water in any snow cover). This enables avoiding the making of estimates about the initial conditions of the catchment's state (see, e.g., Lamb 1999, Boughton – Droop 2003, Hoes – Nelen 2005, Pathiraja et al. 2012). However, the greatest advantage of a continuous simulation is that it can be linked with stochastic weather generators, which enable the generation of various inputs (most often, rainfall amounts and temperatures) of arbitrary lengths. Weather generators preserve the statistical characteristics of observed time series of input variables (see, e.g., Racsko et al. 1991, Chen et al. 2010, Výleta 2013). The RR model can then transform the generated weather data into a time series of generated catchment runoff. Despite the fact that the generated time series preserves the statistical characteristics of the observed time series, they can contain rare combinations of subsequent rainfall events that only occur with a very small degree of probability, thereby causing extreme floods, which are not present in the observed time series of the catchment runoff (Valent 2012a).

In the FFA, which is often used for the estimation of design floods, annual maximum (AM) series of flows or flows above a certain threshold (POT) are used in practise. Therefore, the RR model must be mainly able to satisfactorily simulate extremely high flows. This can be achieved by calibrating the RR model for extreme flows while the proper simulation of low and medium flows is neglected. However, this solution is not suitable, since it does not enable a good simulation of the catchment conditions preceding the flood event. Despite considerable efforts in this area, there is not a united methodology for calibrating RR models to extreme flows. The literature contains several studies dealing with this problem (see, e.g., Paquet et al. 2013, Viney et al. 2009, Tan et al. 2005, Lamb 1999).

This paper presents two new approaches to the calibration of RR models to extreme floods and compares them with traditionally used techniques utilizing the Nash-Sutcliffe criterion. In order to increase the credibility of the presented results, the methodology has been applied to two mountainous catchments situated in the central part of Slovakia (*Figure 1*). The approaches are tested on two nested Slovak mountainous catchments: 1) the Hron at Banská Bystrica (BB) and 2) the Hron at Brezno.

2 DATA

The first catchment is a catchment of the River Hron with an outlet at the Banská Bystrica station. The catchment drains an area of 1768.2 km² and flows in a relatively narrow valley with high mountains on each side. The mean altitude of the catchment is 845.1 mASL with the highest peak at 2030.1 mASL. The average annual precipitation amount calculated for the period between 1961 and 2010 from the area precipitation was 846 mm. A high percentage of the catchment is a national park and is covered with coniferous and deciduous forests. The regime of the catchment runoff has a strong seasonal effect with the highest flows in April and the lowest in the winter. The mean annual runoff calculated for the period between 1961 and 2010 is 25.1 m³/s (447 mm) with minimum and maximum values of 4.9 and 515 m³/s respectively. The flow data were collected for the period between 1.1.1961 and 31.12.2010.

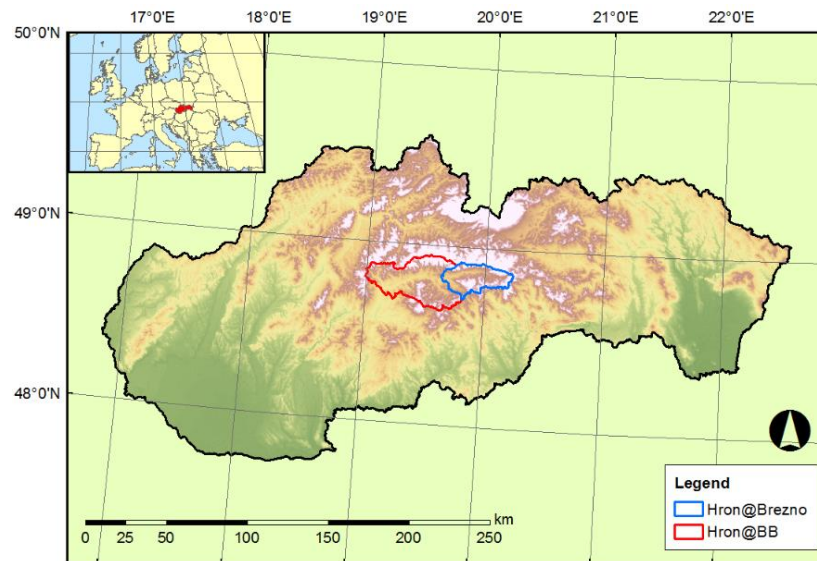


Figure 1. Position of the two catchments: the Hron at Brezno and the Hron at Banská Bystrica in Slovakia (b)

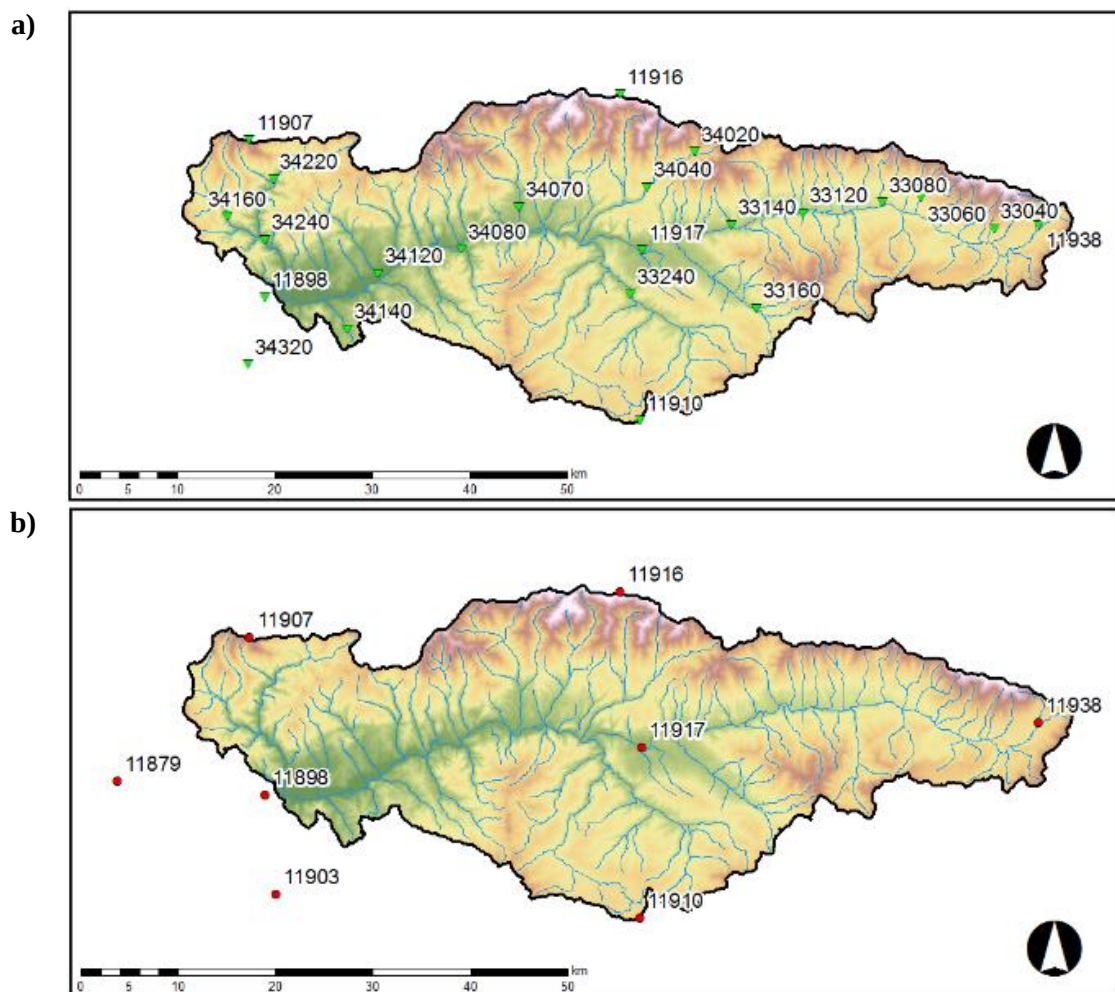


Figure 2. Location of measurement stations in the Hron catchment with the outlet at Banská Bystrica a) 24 rain gauges, b) 7 climatic stations measuring temperatures

The precipitation data were collected from 24 stations (*Figure 2a*) and processed using the inverse distance weighting interpolation method to obtain the catchment's average daily precipitation amounts. The temperature data were collected from 7 climatic stations (*Figure 2b*) and processed using the temperature gradient method to obtain an average daily air temperature for the catchment.

The second catchment is a nested catchment of the River Hron with an outlet at the Brezno station. The catchment drains an area of 578.6 km² and is situated in the upper part of the Hron catchment. The mean altitude of the catchment is 916 mASL with the highest peak of Kráľová Hoľa at an altitude of 1946 mASL. The mean annual precipitation amount calculated for the period between 1961 and 2010 from the area precipitation was 830 mm. The flow regime of the catchment is identical to the regime of the first catchment with the highest flows in April and the lowest in January. The mean annual runoff calculated for the period between 1961 and 2010 is 7.6 m³/s (414 mm) with minimum and maximum values of 1.2 and 178 m³/s respectively. The flows here were also collected for the period between 1.1.1961 and 31.12.2010.

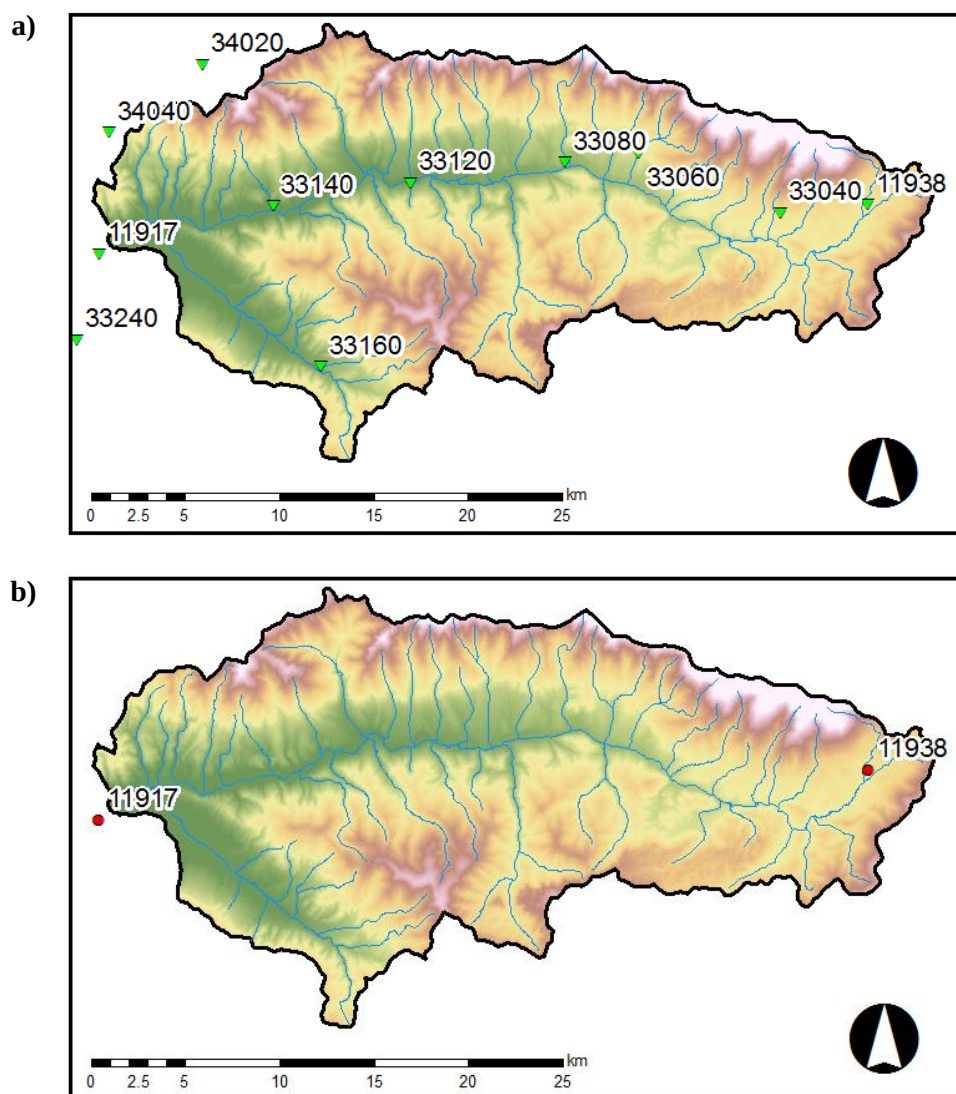


Figure 3. Location of measurement stations in the Hron catchment with the outlet at Brezno a) 11 rain gauges, b) 2 climatic stations measuring temperatures

The precipitation data were collected from 11 stations (*Figure 3a*) and processed in the same way as for the first catchment. The temperature data were collected from 2 climatic stations (*Figure 3b*) and processed using the temperature gradient method to obtain an average temperature for the catchment.

3 METHODOLOGY

This work is focused on the improvement of the calibration procedure of the HRON rainfall-runoff model to better simulate extreme flows. The HRON model is a conceptual lumped model, which works mainly in a daily time-step. It was developed at the Department of Land and Water Resources Management of the Slovak University of Technology and is based on the Swedish HBV model (Bergstrom 1976). The model comprises 3 submodels, each of which represents a different runoff generation process (for the scheme of the model, see *Figure 4*). The model has 14 parameters, which were calibrated using a harmony search algorithm (see, e.g., Valent 2012b or Geem 2009).

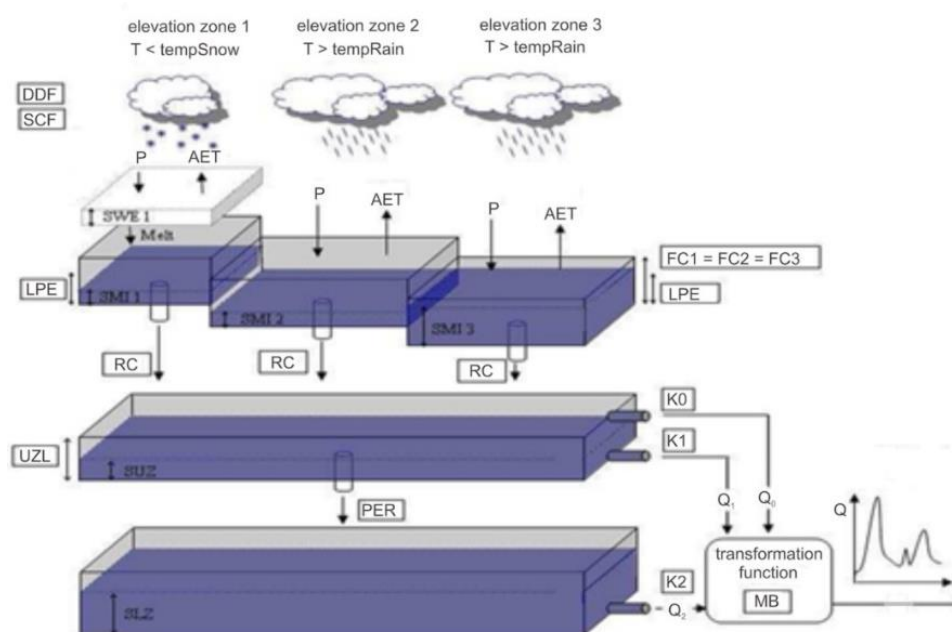


Figure 4. Scheme of the HRON rainfall-runoff model (Valent et al. 2011)

The paper compares the traditionally used calibration technique, utilizing a Nash-Sutcliffe (NS) criterion as the objective function (1) (Nash – Sutcliffe 1970), with two new approaches focused on the calibration to extreme flows. The NS criterion can be written as:

$$NS = 1 - \frac{\sum_{i=1}^n (Q_{sim,i} - Q_{obs,i})^2}{\sum_{i=1}^n (Q_{sim,i} - \bar{Q}_{obs})^2} \quad (1)$$

where $Q_{obs,i}$ and $Q_{sim,i}$ are observed and simulated flows in day i and $\bar{Q}_{obs}$ is the average observed flow.

The first approach is based on the selection of a different objective function. In order to improve the simulation of extreme flows, a new objective function has been proposed. The new objective function takes into account only values that are higher than the 95th percentile of the flows observed. The proposed objective function can be written as

$$f(x) = \frac{(Q_{obs,p95} - Q_{sim,p95})^2}{(Q_{obs,p95} - Q_{p95})^2} \quad (2)$$

where $Q_{obs,p95}$ are all the observed flows that are higher than the 95th percentile calculated from the observed flows; $Q_{sim,p95}$ are simulated flows corresponding to the $Q_{obs,p95}$, and Q_{p95} is the value of the 95th percentile of the flows observed.

The second approach is based on separate simulations of low and high flows. In this approach the HRON RR model utilizes two sets of parameters (the regime switching version of the model). The first set of parameters was used to simulate low flows and was obtained through a traditionally used calibration technique utilizing the NS coefficient (1). The second set of parameters was used to simulate high flows and was estimated by calibrating the model only to the annual maximum floods, where each flood is comprised of the flood peak and two days surrounding it (flood peak $\pm$ 2 days). In order to focus the optimization algorithm on the very extreme flows, an optimization function minimizing the NS criterion for both time and rank-ordered flows was used. The function can be written as

$$f(x) = NS(Q_{T,ord}) + w \cdot NS(Q_{R,ord}) \quad (3)$$

where $NS(Q_{T,ord})$ and $NS(Q_{R,ord})$ are Nash-Sutcliffe criteria calculated for time and rank-ordered flows, and w is a weight (with a value of 2 in this case), which gives the balance between the time (calibration to low and medium flows) and rank-ordered (calibration to high flows) NS criteria (Paquet et al. 2013). Both of the parameter sets were then combined into the switching version of the HRON RR model. The decision as to whether the current flow is considered low or high is taken based on the threshold value of the simulated flow from the previous day (the first flow is calculated as low). The threshold for determining whether the flow is low or high was also calibrated for each catchment individually.

4 RESULTS

In the first step the HRON RR model was calibrated by the traditional approach using the NS criterion as an objective function. In both cases the model was calibrated for the whole period between 1961 and 2010. The overall quality of the simulation was assessed by calculating the NS criterion values (0.744 for the Hron at BB and 0.780 for the Hron at Brezno) and by comparing the observed and simulated interannual flow regimes (*Figure 5*). The quality of the simulation of the extreme flows was assessed by comparing the empirical cumulative distribution functions (ECDF), which were calculated for the observed and simulated series of the annual maximum (AM) flows (*Figure 6*). *Figure 6* shows that both models underestimate extreme flows, which is not acceptable in the FFA. The main reason for this is the NS criterion, which takes into account the flows (low and medium ones) which are the most frequent and thus have the largest impact on the NS value.

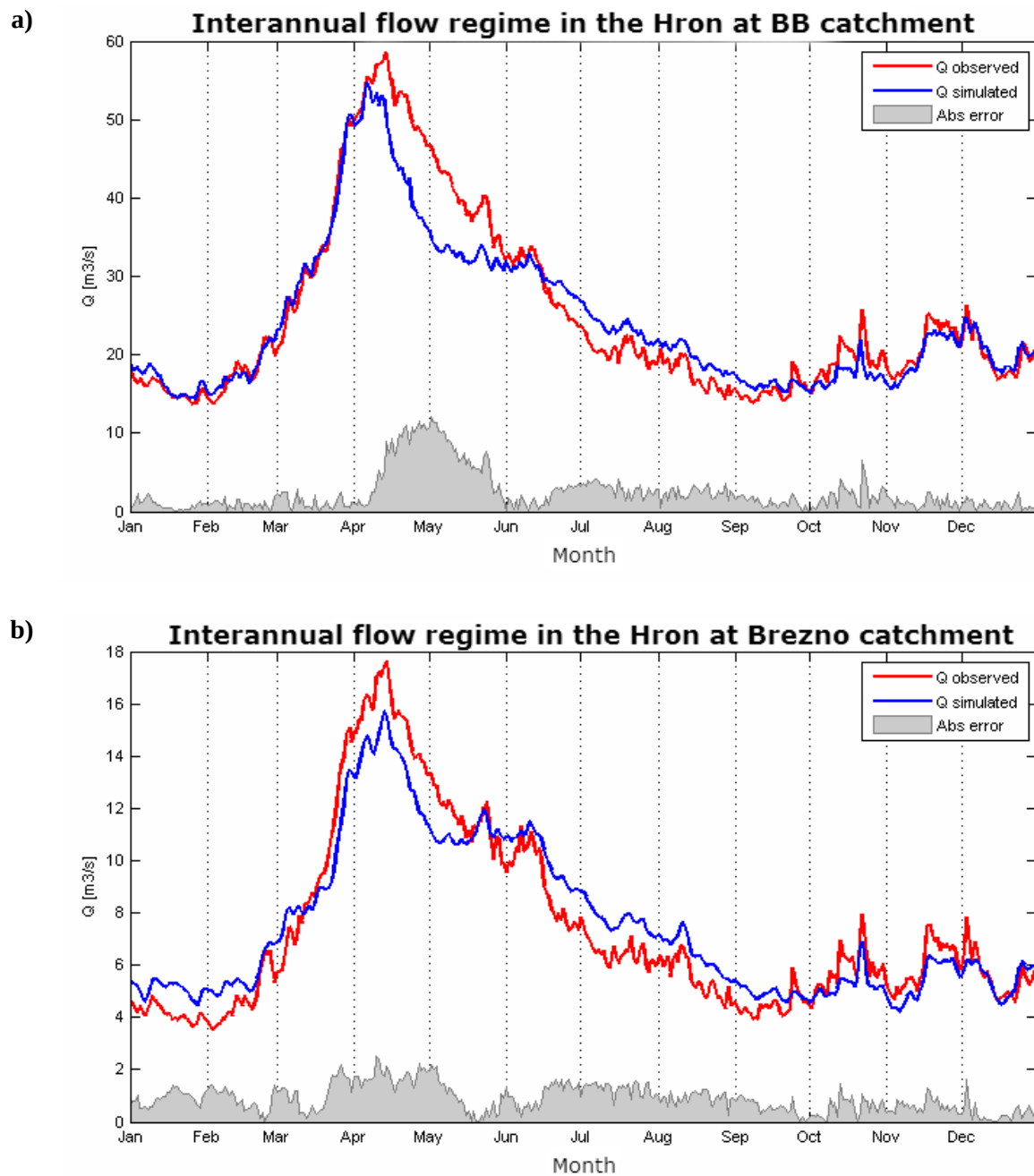


Figure 5. Comparison of observed and simulated interannual flow regimes for the Hron catchments at BB (a) and at Brezno (b). Calculated by the HRON model using the NS criterion (1) as an objective function

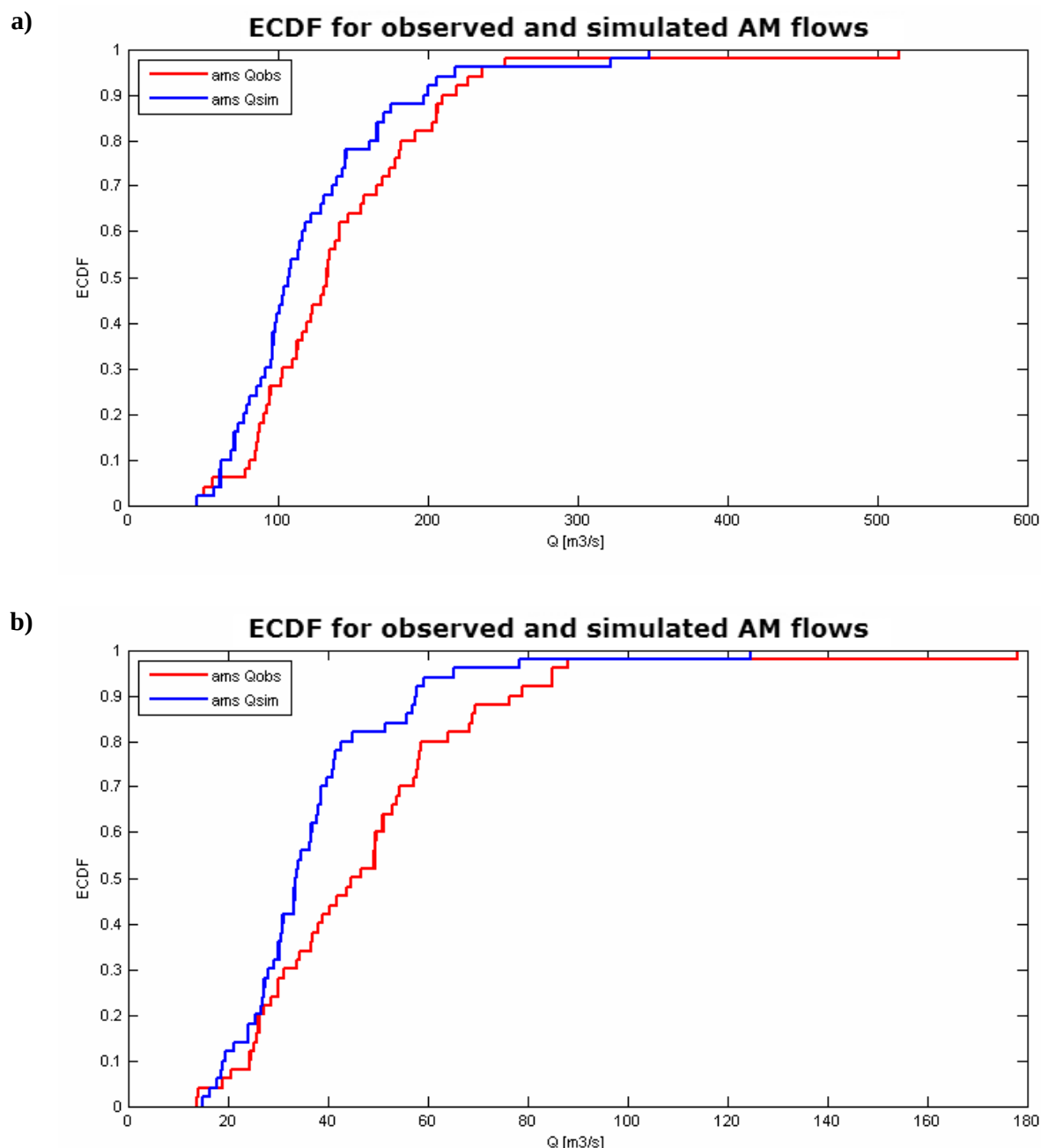


Figure 6. Comparison of the ECDF calculated for the observed and simulated AM flows for the Hron at BB (a) and the Hron at Brezno (b). Calculated by the HRON model using the NS criterion (1) as an objective function

In the next step a new optimization function has been used to improve the simulation of extreme flows. The use of the proposed optimization function (2) had a positive effect on the simulation of extreme flows, especially in the case of the Hron catchment at Brezno (Figure 7b). However, the calibration of the model to the values higher than the 95th percentile of the observed flows resulted in the model not being able to reproduce the low and medium flows (Figure 8); thus its application is very limited to FFA, when it does not enable correct the simulation of conditions preceding flood events.

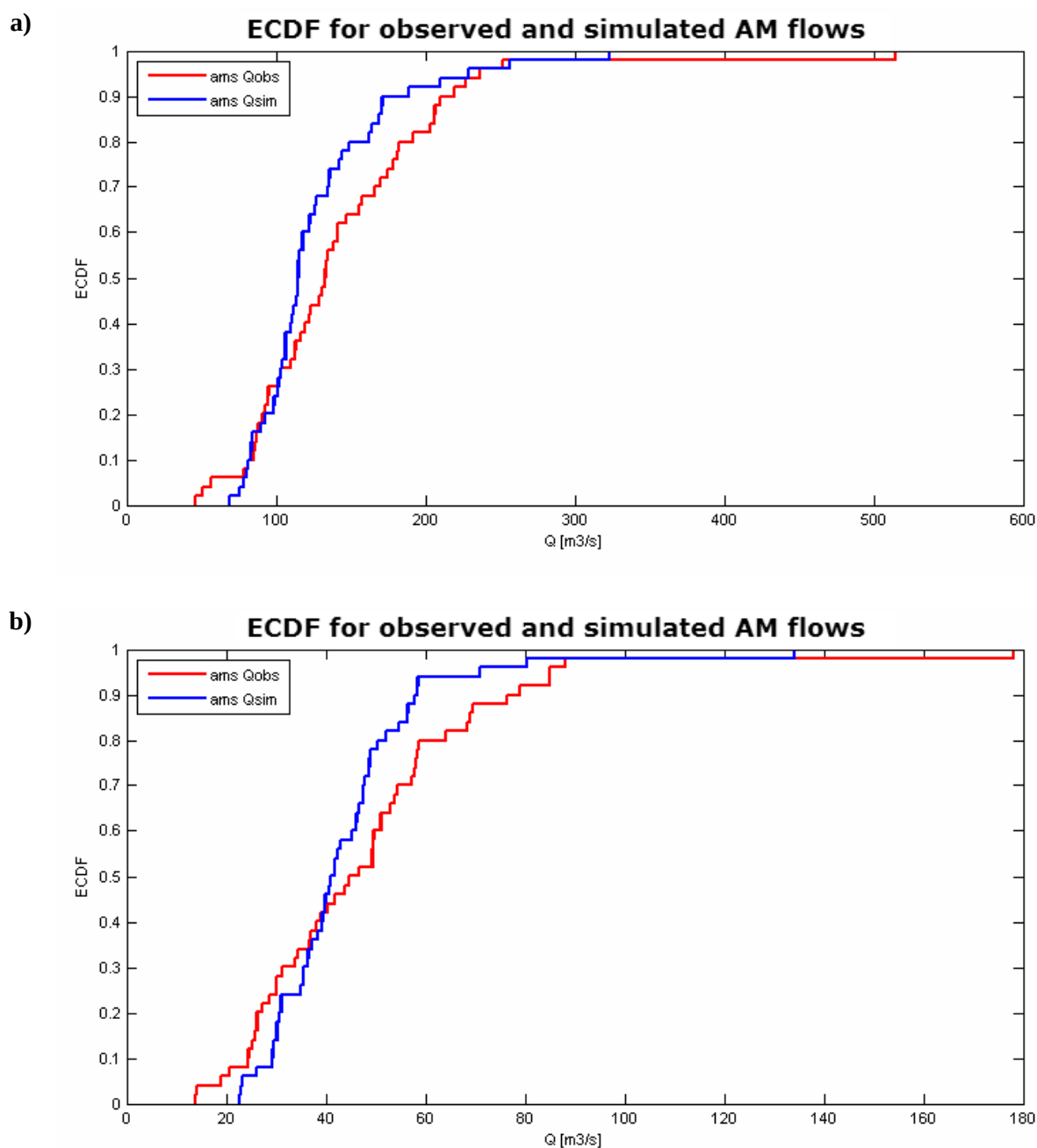


Figure 7. Comparison of the ECDF calculated for the observed and simulated AM flows for the Hron at BB (a) and the Hron at Brezno (b). Calculated by the HRON model using the objective function, which compared only the values higher than the 95th percentile of the observed flows (2)

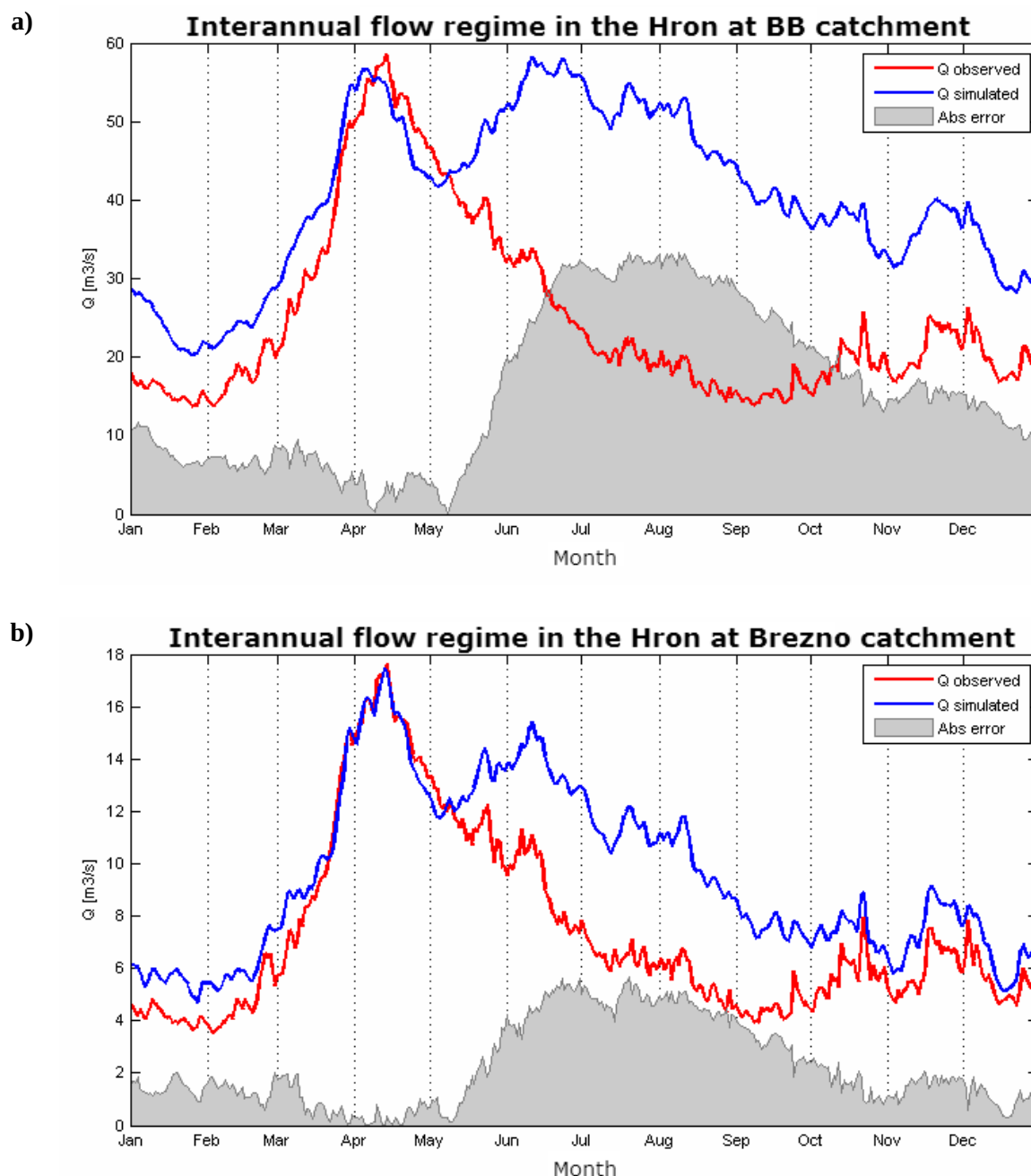


Figure 8. Comparison of the observed and simulated interannual flow regimes for the Hron catchments at BB (a) and at Brezno (b). Calculated by the switching version of the HRON model using the objective function, which compared only the values higher than the 95th percentile of the observed flows (2)

The second approach focuses on improving the simulation of extreme flows while maintaining the good simulation of low and medium flows. It utilizes two sets of parameters to separately simulate low and high flows. The threshold determining whether the flow is low or high was calibrated and was set to be 70.25 and 20.78 m^3/s for the Hron at BB and the Hron at Brezno, respectively. By using separate simulations of the low and high flows, a significant improvement of the simulation of the extreme flows has been observed (Figure 9), while preserving the good simulation of the low and medium flows (Figure 10).

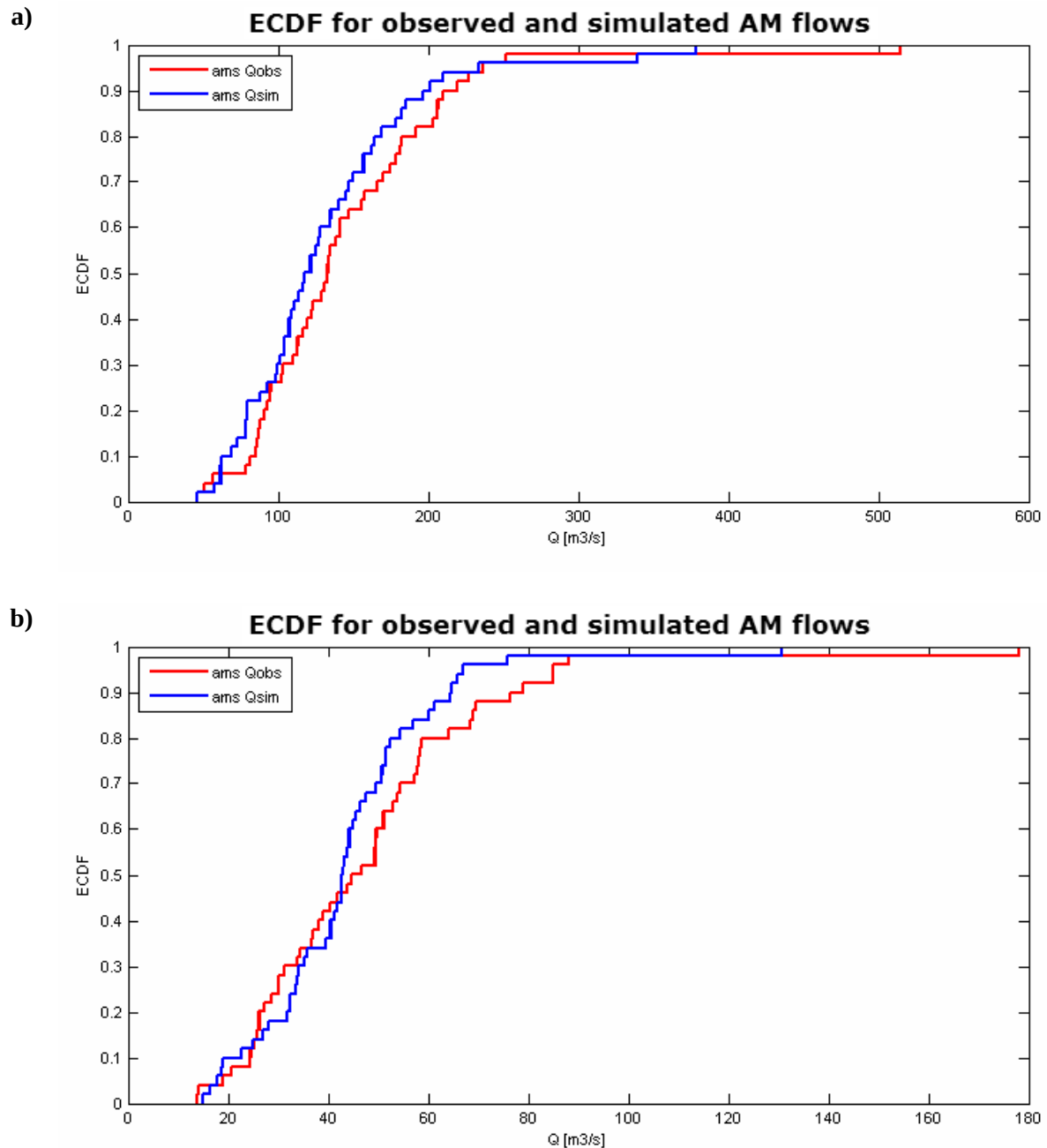


Figure 9. Comparison of the ECDF calculated for the observed and simulated AM flows for the Hron at BB (a) and the Hron at Brezno (b). Calculated by the switching version of the HRON model using the objective function (2) to calibrate parameters for the low flows and (3) for the high flows

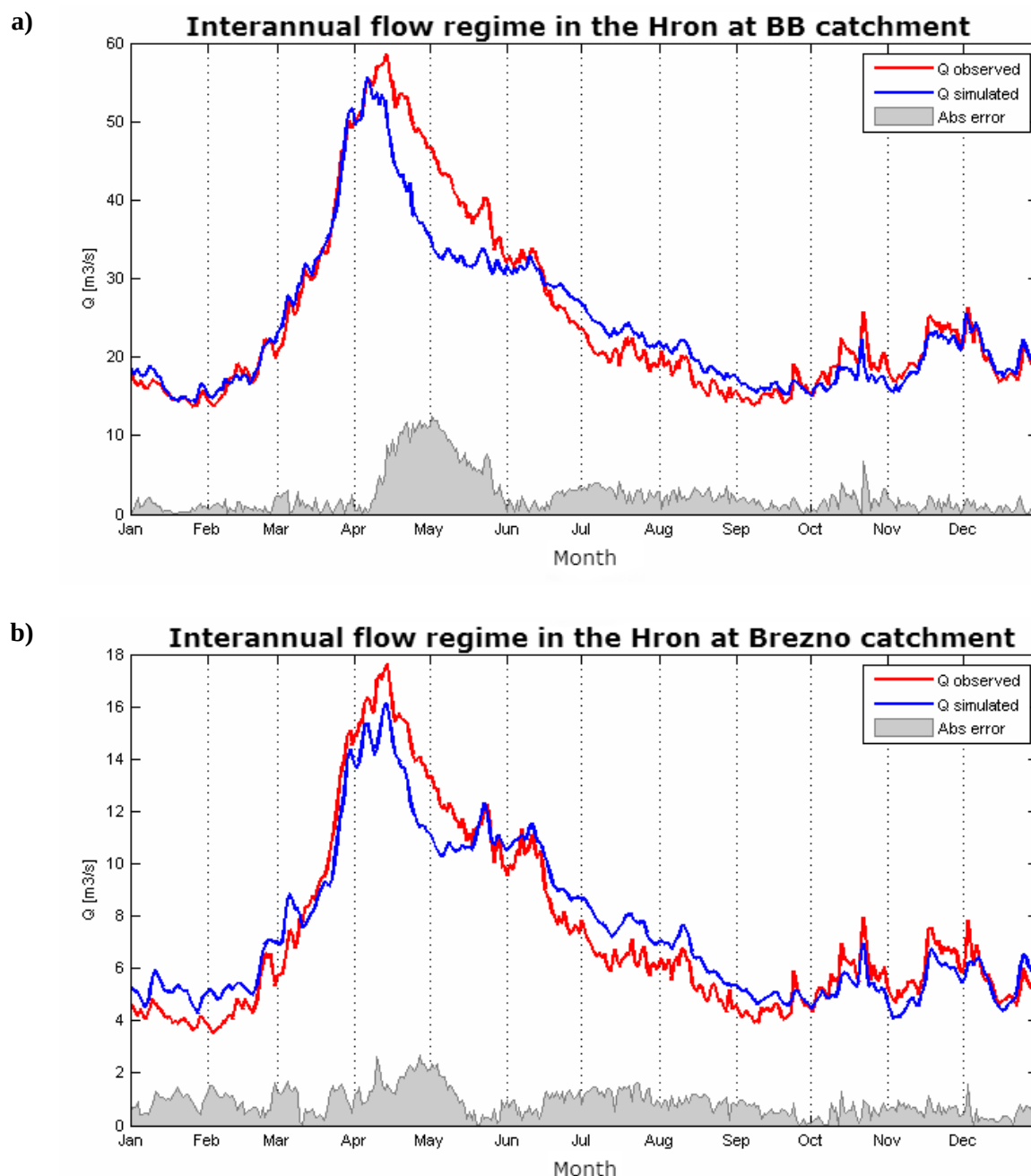


Figure 10. Comparison of the observed and simulated interannual flow regimes for the Hron catchments at BB (a) and at Brezno (b). Calculated by the switching version of the HRON model using the objective function (2) to calibrate parameters for the low flows and (3) for the high flows

5 SUMMARY AND CONCLUSIONS

The main objective of this paper was to improve the traditionally used calibration techniques of the RR models for use in FFA. Traditional approaches for the calibration of RR models are known for not being able to satisfactorily simulate extreme flows, which is caused by using optimization functions such as the Nash-Sutcliffe criterion or mean squared error. The correct

simulation of extreme flows is vital in FFA, since only the most extreme flows are used in the analysis (annual maximum series or peaks over threshold).

In the first case study of the paper a traditionally used method for calibrating an RR model was used. The method utilized a NS criterion as an objective function and, for both catchments, it proved to be good in maintaining the overall flow regime (*Figure 5*). The quality of the simulation of extreme flows was assessed by comparing the ECDFs calculated for both the observed and simulated AM flows (*Figure 6*). They proved that the simulation of extreme flows was unsatisfactory and that its use in the FFA is not recommended.

In the next part an alternative approach for calibrating RR models to extreme flows was proposed. The approach utilizes a new objective function, which compares only values higher than the 95th percentile of the observed flows. The improvement of the simulation of the extreme flows was at the expense of the simulation of the low and medium flows. This makes this approach virtually unusable for tasks such as determining flood volumes or durations.

The second approach was comprised of separate simulations of the low and high flows. The low flows were simulated using the same set of parameters calibrated using the traditional approach, while the high flows were simulated using the parameters calibrated to the annual maximum floods (peak $\pm$ 2 days) and an objective function minimizing the NS criterion for both the time and rank-ordered flows. The thresholds determining whether a flow is low or high were estimated for each catchment and were set at 70.25 and 20.78 m³/s for the Hron at BB and the Hron at Brezno, respectively. Using this approach the best simulation of the extreme flows was observed (*Figure 9*), while preserving a good simulation of the low and medium flows (*Figure 10*).

The results of this work show that further work in the calibration of RR models for the needs of FFA should focus not only on the development of new objective functions, but also on investigating the effects and possibilities of using RR models with multiple regimes.

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Vol. 4, Nr. 1, 2014

Dénes BARTHA, Márton KORDA, Gábor KOVÁCS and Gábor TÍMÁR:

Nationwide comparison of potential natural forest communities and current forest stands ... 7–21

Abstract – Results of nationwide analysis of Hungarian Forest Stand Database (date 01. 01. 2012) have been presented in this publication. We defined the potential natural forest communities of all forest compartments by the method of site evaluation. Comparison of potential natural forest communities and current forest stands makes it possible the analyses of relationship between the potential and current forest communities nationwide. This study makes an attempt to discover the background of current forest communities surveying the site conditions and former landscape use of forest compartments.

Ágnes CSISZÁR, Márton KORDA, Gergely ZAGYVAI, Dániel WINKLER, Viktor TIBORCZ, Péter SÜLE, Dean ŠPORČIĆ, Dénes NAÁR and Dénes BARTHA:

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Ádám SILNICKI, Gergely ZAGYVAI and Dénes BARTHA:

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Károly RÉDEI, János RÁSÓ, Zsolt KESERŰ and János JUHÁSZ:

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Abstract – The paper analyses the stand structure and yield of black locust (*Robinia pseudoacacia*) stands mixed with grey poplar (*Populus × canescens*) in various proportions, partly applying a new methodological approach. The main stand structure and yield factors were determined separately for each species, measured stem by stem, using the volume functions prepared for each species. The ratio of the volumes of the species (RVA and RVB) was determined based on the particular yield tables. A close relationship has been found between the ratio of relative volume and the proportion of the species calculated by number of stems. The relative surplus in the volume of the mixed stands varied between 1.32–1.80 at age 16 and 21 years compared to the control, i.e. the yield of pure stands of the species concerned. The investigations have also proven that if two species have a fast initial growth rate and a similar rotation age, they can be planted in mixed stands resulting in mutual growing advantages.

Norbert FRANK, Tamás FÜLÖP and Ádám FOLCZ:

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Abstract – Among the tree forest blocks managed with transformation silviculture system by Zselic Forestry, we have made full forest inventory in the Töröcskei-Block on 21.5 respectively 43.75 ha. We have analyzed the stand structure of European Beech, Hornbeam, Silver Lime, Sessile Oak and Turkey Oak. In the course of comparison, we experienced that the variety of height and the volume of hornbeam is different but in the case of the others we admixed the tree species and only the volume was different. In the face of the results we have made a D-test (Welch's-test) of height and volume of hornbeam, respectively the result of the T-test of all the other tree species. Based on the results ($p=0.05$) the height and volume of the two sampling plots equaled.

Éva SALAMON-ALBERT, Péter LÖRINCZ and Ágnes CSISZÁR

Ecophysiological responses of woody regrowth under gap-phase regeneration in Turkey oak – sessile oak forests ... 83–94

Abstract – A gas exchange based ecophysiological performance of five regrowth species has been investigated in a xero-mesophilous oak forest. Seasonal light responses, capacities and variability of assimilation, transpiration and water use efficiency under light saturated conditions are discussed to reveal ecophysiological characteristics of the species in gap-phase dynamics. Species present assimilation maximum in autumn, followed by a continuously increasing carbon-dioxide fixation rate through the seasons. Transpiration peak is manifested differentially in summer and autumn. Autumn maximum of photosynthetic water use efficiency as the ratio of carbon input and water output is detected for all studied species. Limitation of gas exchange parameters is highly indicated by low level of water use efficiency in the summer season in case of *Fraxinus ornus*, *Quercus cerris* and *Q. petraea*. *Carpinus betulus* turned out to be a source saving species by a moderate gas exchange rate in every season. According to the moderate rate of carbon assimilation and transpiration but the highest rate of water use efficiency, *Rubus fruticosus* can be the most effective species in the early stage of gap-phase dynamics. Assimilation to transpiration rate in spring and summer is strongly coordinated, water use efficiency is a species and season dependent aspect. Autumn and summer season water use efficiency can serve an appropriate tool for indicating environmental limitation and scaling habitat suitability of the species in dry oak forests.

Éva KIRÁLY and Péter KOTTEK:

Estimation of the stocks and stock change of the Hungarian harvested wood product pool using the methodology of 2013 IPCC Supplementary Guidance ... 95–107

Abstract – We estimated the amount of carbon stored in the Hungarian harvested wood product pool, and the amount of annual inflow and outflow from the pool for the time period 1900–2020. We studied national and international data sources in order to find the best available and consistent data on production and trade. Because both the dataset and the methodology, i.e., the 2013 IPCC Supplementary Guidance that were used for this study differ from those in earlier studies, the results obtained are different as well. We now estimate that the carbon accumulation of the Hungarian HWP pool amounts to 9 million tonnes of carbon, and the average of annual net emissions from the pool is around -100,000 tonnes CO₂.

Erika HORVÁTH-SZOVÁTI and Andrea VÁGVÖLGYI:

Analysis yields of energy plantations ... 109–118

Abstract – The mini-rotation energy plantations are important on the one hand as a source of renewable energy, on the other hand, makes it useful the not suitable for agricultural use lands. We try to give an answer to the question, under what climate and soil conditions is the increase the most significant. Large number of variables, in the experiment was reduced to a minimum by means of multivariate statistics (principal component analysis and factor analysis). We found that the yields are affects primarily by temperature, by soil pH, by CaCO₃ content and by Arany's value. As in the pilot areas significant difference in terms of rainfall was not, so the effect of this factor reduced the minimum.

József PÉTERFALVI, Péter PRIMUSZ, Gergely MARKÓ, Balázs KISFALUDI and
Miklós KOSZTKA:

**Testing of subgrade stabilized with lime on an experimental road section
... 121–134**

Abstract – When constructing forest roads on cohesive soil, it is suitable to substitute sandy gravel sub-base course with lime stabilized subgrade. This solution reduces the volume of construction materials and at the same time moderates the unfavourable properties of cohesive soils. If the bearing capacity of the lime stabilized layer can be included in the bearing capacity of the pavement, then the costs of road construction can be reduced by reducing the thickness of the crushed stone course. To achieve this, the testing of the bearing capacity of the lime stabilized layer is necessary. It is suitable to complete the test on an experimental road-section practically in forest circumstances. Such an experimental road-section was constructed in cooperation between the Institute of Geomatics and Civil Engineering and the Zalaerdő Forestry Closed Company, within the frame of the Regional University Knowledge Centre of Forest and Wood Utilization. The results of this test clearly demonstrate that the local cohesive soil stabilized with suitable lime feeding can be the bearing layer of the pavement of forest roads.

Balázs KISFALUDI:

Determining forest road traffic by camera surveillance ... 135–145

Abstract – Most of the forest roads are used not only by forestry vehicles and staff, but by local inhabitants, tourists and others. Although heavy traffic is generated mostly by the vehicles connected to forestry operations. Different user groups have different needs against the geometry, the pavement type and the pavement condition of forest roads. To determine these needs, the traffic on the segments of a forest road network must be analysed. In this work, a traffic counting system and the obtained data are presented. The system consists of two retro-reflective photoelectric sensors, a safety camera and a control unit. A photo is taken whenever the light beam is interrupted. Combining the images with the data log of the sensors, the direction, the speed and the temporal distribution of the users of a particular forest road could be deduced. Based on this data, a proposal is made for the method of traffic analysis on whole road networks. As a result of this analysis the preferences of the forest road user groups could be determined. This information could be taken into account in the planning process of new forest road networks or the development of existing ones.

Tamás BAZSÓ, Péter PRIMUSZ and Márk NÉMETH:

The application of TruPulse laser ranger for forestry surveying ... 147–158

Abstract – In the last century the Wild T0 compass theodolite was the standard instrument of forest mapping and inventory. Nowadays this instrument is almost disappeared from the forestry surveying. Instead of theodolite we use GNSS instruments, which are easy to use even for not professionals. Data management is much faster with this instrument because of its compatibility with GIS software, but sometimes its accuracy is not so good as in the case of theodolite. In these days we can find digital surveying instruments, which can be operated by simple methods. The accuracy and efficiency of these instruments are suitable for today's engineers, and the processing of the data can be supported by geoinformatics. We examined the accuracy and effectiveness of the instrument, TruPulse 360B by test measurements. This instrument is a possible alternative of Wild T0, because we also can measure magnetic horizontal angle with it. We established a test field with surveying accuracy for the test measurements, where we can examine many kind of surveying methods. We found that the required accuracy can be achieved applying appropriate measuring mode and processing method. Therefore we can apply this instrument for engineer project.

Miklós MOLNÁR:

Significance of wood small-reed (*Calamagrostis epigeios*) in Hungarian silviculture by questionnaire survey ... 159–169

Abstract – Coverage, richness and composition of bryophytes were compared between spruce and beech forest stands in the Sopron mountains. The highest coverage of bryophytes species in beech forests had *Hypnum cupressiforme*, which was followed by terricolous species like *Atrichum undulatum* and *Dicranella heteromalla*. The most dominant species in the spruce stands was *Brachythecium velutinum*; *Brachythecium rutabulum* and *Fissidens taxifolius* had slightly lower cover. The cover of bryophytes in beech stands was twice as high as in spruce stands. The total bryophyte coverage was very small in both forest types. The proportion of stands without bryophytes was the same in beech and spruce forest stands. Greater richness of bryophyte was found in beech stands than in spruce stands. The most frequent species were *Hypnum cupressiforme* and *Brachythecium velutinum* in both forest stands. The bryophyte flora was richer in native beech forests, than in spruce stands, which were planted on natural beech forests sites. However, the bryophyte composition of beech and spruce stands show considerable similarity. Generally, the older spruce plantations had unfavorable effect on the bryophyte diversity.

Dániel ANDRÉSI and Ferenc LAKATOS:

Investigations of ground beetle assemblages in an artificial gap of Balaton Uplands (Hungary) ... 171–183

Abstract – In 2013, the ground beetle assemblages of an artificial gap were studied in the field of Bálint-hegyi Erdőbirtokossági Társulat, in the subcompartment of Zánka 1B. We used 10 pitfall traps filled with acetic acid solution. We collected altogether 4357 individuals of 20 carabid species. In our research, we examined the number of species and the number of individuals by dates and habitats. We trapped the highest number of species (16 species) on the 28th of June, while we trapped the highest number of specimens (1422 specimens) on the 31th of July. The number of species was the highest in the gap edge and in the mesic part of the forest (16 species each). The number of specimens was the highest in the gap edge (1308 specimens). We examined the dominance of the species and the distribution of the fauna elements. In all habitats *Carabus convexus* *convexus* had the highest dominance values. The

ground beetle fauna of the investigated locations (gap, gap edge, closed forest, mesic part of the forest) were compared with various ecological parameters (diversity, the level of consistency, similarity measures and hierarchical cluster analysis, based on Bray-Curtis).

Bálint HORVÁTH and Ferenc LAKATOS:

Study on the diversity of nocturnal Macrolepidoptera communities in different age sessile oak – hornbeam forests ... 185–196

Abstract – Macrolepidoptera communities and their diversity were compared in different age sessile oak-hornbeam forests, in the Sopron Mountains. The study was carried out in 2012-2013 from the end of March until early November each year, using portable light-traps. Our goal was to find any correlation between Lepidoptera diversity and the age of the forests. We used community and ecological characteristics to determine and compare Lepidoptera assemblages (Shannon and Simpson diversity indices, Pielou's evenness indices, Community dominance indices, Bray-Curtis similarity indices, Rényi's diversity ordering). Our result did not show a direct correlation between the Macrolepidoptera diversity and forests' age. However, our conclusions support the high influence the abundance of different vegetation layers on macromoth communities.

Gábor NAGY, Kornél ÁCS, Ágnes CSIVINCSIK, Gyula VARGA and László SUGÁR:

The occurrence of thorny-headed worm *Macracanthorhynchus hirudinaceus* in Transdanubian wild boar populations in relation to certain environmental factors ... 197–206

Abstract – During the hunting season 2012-13 we investigated occurrence of the Thorny-headed Worm *Macracanthorhynchus hirudinaceus* in 7 hunting areas. We dissected 618 wild boar (*Sus scrofa*) viscera. Worms were present in 4 areas, with a prevalence varying between 4.3-100%. *M. hirudinaceus* mostly occurred in areas characterised by sandy soils and a high density of cockchafers (*Melolontha* spp., *Rhizotrogus* spp.).

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Ferenc JANKÓ:

From regional to global climate change: Three chapters of science history from Hungary ... 9–20

Abstract – I show three relative brief episodes in relation to the history of Hungarian climate research. I investigate the peak of the climate controversy of the Great Hungarian Plain, i.e. the Kaán–Réthly debate, where not only two different personalities, but also two different imaginations of environmental or climate change faced with each other. Second, I show the effect of extreme weather on the media and public discourse through newspaper coverage, pointing out the similar attitude of the press compared to the present. Third, I recall the circumstances of the introduction of the global climate change theory in Hungary. I highlight that a representative of the old idea, i.e. stable climate with climatic fluctuations, raised the new theory first, but the new generation extended it with international impulses, partly with Soviet transmission in the background

Bence BOLLA, Péter KALICZ and Zoltán GRIBOVSKI:

Water balance of forests in Kiskunság sandridge ... 21–31

Abstract – In this article we would like to give a picture of the characteristic features of sand-land forests concerning their water balance, and in relation to forest hydrology, that is we would like to outline how to apply those features in the course of nature conservation treatment. We based our survey both on special literature and on exchanges of practical experience with experts. More detailed investigation of the general hydrology of Duna-Tisza Sandridge started in the 1970s and expert opinions differ widely over the effects of crops on ground water level, that is, whether we can establish a connection between the growing afforestation in the area and the decrease in groundwater levels. This study confirms that we need to broaden our knowledge about this special field during forestry and nature protection management, and to explore the water management of sand-land sites, which are characterized by dry growing features, even more in the future. The local measurements and experiences must be determining in rational management and conservation treatment, because significant part of forests are in protected areas in Kiskunság.

Imre CSIHA and Zsolt KESERŐ:

Investigation of rooting zone of forest association growing under drying sandy site conditions ... 33–42

Abstract – Today the Hungarian forest-steppe oak stands are grown mainly on unfavourable sandy sites. On these areas both the precipitation distribution and the water regime are unfavourable and the groundwater is in inaccessible depth for stands. In spite of that a lot of old high quality stem can be found in the investigated forest associations according to our experience the associations' regenerations sometimes encounter insolvable difficulties. In spite of that the rate of growth of the present stand relates to sufficient water quantity the growing of the planted seedlings and sowings is slow in the different forest regenerations. The state of health of the regrowth is bad, the stand becomes thinner and invasive weeds occupy on the area after a few years. We carried out root excavations to find out the reason of the different growth pattern between the regrowth and the original stand. On the area the investigated root systems of the three tree species – pedunculate oak (*Quercus robur*), white poplar (*Populus alba*) and common ash (*Fraxinus excelsior*) – show that the present old stand didn't evolve by means of dry sandy site but it developed due to the effect of the covered meadow soil.

Miklós MANNINGER and Zoltán PÖDÖR:

Characterization of the temperature and precipitation condition of Zala County ... 43–54

Abstract – Considering the possible impacts of the climate change we investigated the time series of precipitation ranging from 1901 to 2013 at Nagykanizsa and Zalaegerszeg in Zala County. Firstly we aggregated seasonal sums from the monthly data according to the periods of the water cycle in the forest (storage: Nov-Apr, main consumption: May-July, maintenance: Aug-Oct, hydrological year: Nov-Oct), then we studied the distributions and trends in time, and analysed the break points. We also carried out these analyses on the temperature data of Nagykanizsa (1972–2013). The results show great variety in the seasonal precipitation sums (CV is about 30%), while the CV of the seasonal mean of the temperature – except from the storage period – is smaller (5–7%). Depending on the station and the period, mostly a decreasing trend can be detected for precipitation and the seasonal means of the temperature are increasing significantly. Break points appear in the time series of the precipitation from 1941 till 2000, but they occur mostly in different years on the different stations, thus they are not valid for the whole region. In the time series of temperature there are break points in the recent past.

Gábor ILLÉS, Gábor KOVÁCS, Annamária LABORCZI and László PÁSZTOR:

Developing a unified soil type database for County Zala Hungary using classification algorithms ... 55–64

Abstract – Within the framework of AGRÁRKLÍMA project we prepared soil maps for both forest- and croplands of Zala County of Hungary. To achieve this we used a GIS database consisting of data on geology, relief, hydrology, (referred as environmental variables) and forestry, supported with data from the Digital Kreybig Soil Information System. The available set of site data from forestry and agricultural database was evaluated in relation to the environmental datasets. This process aimed at setting up signatures for all soil types by signature of the most strongly related environmental feature sets for each soil type. Using these signatures we trained hierarchical and non-hierarchical classification tools to identify the spatial extent of soils in Zala County. Neural networks were found to be the most effective

mapping tool. Making a validation with a data set of known soil characteristics we found 67% correct classification rate for the county. Additionally, we set up a joint soil type database for County Zala.

Péter CSÁKI, Péter KALICZ, Gergely CSÓKA, Gábor Béla BROLLY, Kornél CZIMBER and Zoltán GRIBOVSKI:

Hydrological impacts of different land cover types in the context of climate change for Zala County ... 65–76

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Gábor ILLÉS, Tamás KOLLÁR, Gábor VEPERDI and Ernő FÜHRER:

Forests' yield and height growth dependence on site conditions in County Zala Hungary... 77–89

Abstract – One of the upcoming most severe issues in forestry in relation with climate change is set up a sound base for correct choice of applicable species. The current practice is unable to entirely solve this problem. Within the framework of AGRÁRKLÍMA project we investigated the site dependence of height growth for some species in County Zala. For the study we used data of different sources: forest management plans, long-term experimental plots of NARIC FRI for yield assessments, and site characteristics. We identified the factors from the dataset, which have main influence on height growth of the following species: beech, sessile oak, turkey oak, scots pine. Using multiple regressions we derived functions to assess height growth of above species. We found biologically high values of R-square between 0.65 and 0.87. Beside the age of the stands the most influencing factors were: forest aridity index, rootable depth, and soil texture. Using the regression equations and the new yield tables for the county we prepared maps showing the expected change in yield classes and growth-capacity according to the increase of aridity index due to climate change. This method makes us able to support yield based choice of tree species for future afforestations and regenerations.

Anikó HORVÁTH and Csaba MÁTYÁS:

Estimation of increment decline caused by climate change, based on data of a beech provenance trial ... 91–99

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responses of populations to sudden climatic changes, simulated by transfer. Plot averages of 15-year diameter, measured on the 5 largest trees per plot were analysed. Out of the climatic variables, the ones determined by summer temperatures (Tmax, TQW) and drought conditions (DMI, EQ) were significant. Not surprisingly, Ellenberg's drought index has shown the best correlation and was selected for the characterization of ecodistance. The climatic distance between the provenance origin and the test site, and the 15-year diameter data were used to establish a linear transfer function of high significance ($p=0.0006$). The regression (Fig. 3) indicates a monotonous decline which has no maximum value at "0" ecodistance, and may be used for the estimation of growth decline caused by changing climatic conditions.

Gábor VEPERDI:

Determination of site quality index based on the mean annual increment of the growing stock at or near the rotation age ... 101–107

Abstract – Recent research activities have proven that in case of new local yield tables the mean annual increment of the total production cannot be used to determine site quality index as total production is not known in most cases. This paper suggests using the mean annual increment of the growing stock as a basis of determination of site quality index. On the other hand, this value is not comparable with site quality indices derived from existing global yield tables. The paper presents a new method of site classification where site quality index is derived from growing stock data in global yield tables. Both a graphical method and numeric values are presented.

Ernő FÜHRER, Imre CSIHA, Ildikó SZABADOS, Zoltán PÖDÖR and Anikó JAGODICS:

Aboveground and belowground dendromass in a stand of Turkey oak ... 109–119

Abstract – In general view, the role of forests in carbon cycle is considered to be positive in reference to the impacts and mitigation of climate change. To verify this by results in Hungary, we have to assess the amount of carbon stored in forests in Hungary as a basis for comparison. Expecting warmer and drier climate as an effect of the climate change, we have to prefer the native tree species that are able to survive and maintain vitality under the new conditions. Therefore in a stand of Turkey oak we investigated the compartments of aboveground and belowground dendromass in terms of carbon equivalent. According to the results, 70% of the total dendromass was above and 30% of it was below the ground. Percentage of the compartments in descending order are as follows: stems: 55%, roots 24%, branches 13%, trunks 6% and foliage 2%. The ratio of aboveground (without foliage) and belowground carbon stock is 2.3. Taking our previous results of other forest stands into account, we could determine the correlation of Forestry Aridity Index (FAI) and this ratio. Hence the carbon amount in belowground dendromass can be estimated based on the stand volume and this climate-dependent ratio.

András BIDLÓ, Péter SZÜCS, Adrienn HORVÁTH, Éva KIRÁLY, Eszter NÉMETH and Zoltán SOMOGYI:

The effect of afforestations on the carbon stock of soil in Transdanubian Region (Hungary) ... 121–133

Abstract – Forest ecosystems are the most important carbon sinks, and the forest soils play an important role in the global carbon cycle. We have little data on the carbon stock of soils and its change due to human activities, which have similar value to carbon content of biomass. In our investigation we measured the carbon stock of soil in six stands of *Quercus*

petrea and six stands of *Robinia pseudoacacia* after afforestations. We compared the carbon stock of forests with that of neighboring arable lands of the same soil conditions. We found larger quantity of carbon under the forest stands than in the arable lands (including the forest litter). However, differences were less clear in case of soil layers. In any event, the afforestations increase the carbon stock of soil (including the forest litter), and contribute to the mitigation of atmospheric carbon-dioxide

Klára CSEKE, Szilvia JOBB, András KOLTAY and Attila BOROVICS:

The genetic pattern of oak decline ... 135–147

Abstract – We have analysed the genetic pattern of oak decline through the comparison of subpopulations composed viable and declined trees growing close to each other on various stands. The applied sampling method excluded most of the site effects influencing viability. For the genetic investigation 6 nuclear microsatellite loci (ZAG1/5, ZAG96, ZAG110, ZAG9, ZAG11, ZAG112) and 7 isoenzyme loci (IDH_B, PGI_B, AAP_A, AAT_B, ADH_A, SKDH_A, PGM_B) were applied. The genetic diversity of the analysed subpopulations were evaluated by different indices, such as number of alleles, effective number of alleles, Shannon diversity index, number of private allele, expected- and observed heterozygosity, fixation index. The different tendency of results regarding isoenzyme markers in case of pedunculate and sessile oaks was a conspicuous speciality of the study. Higher allele diversity was detected in the declined pedunculate oak subpopulation, while in case of the sessile oaks the viable subpopulation showed higher values. A very similar tendency could be revealed with the calculation of fixation index based on the heterozygosity values. In case of the microsatellite markers the outstanding allelic diversity of the viable pedunculate oak subpopulation was remarkable. Based on the genetic distance among the analysed subgroups the two oak species compose two distinct clusters, and also the viable and declined subpopulations separate within the two main clusters.

Imre BERKI, Ervin RASZTOVITS and Norbert MÓRICZ:

Health condition assessment of forest stands – a new approach ... 149–155

Abstract – The drought induced oak decline has been continuously observed for more than three decades in Hungary. We introduced a novel health assessment method based on the evaluation of the decline of stand density (compared to the density of the fully stocked stand) caused by drought-induced tree mortality. The health condition of the stand can only be assessed, if the decreased relative stand density due to the mortality is further reduced through concerning the health condition of the survived trees. Stands for the assessment were selected along a climatic gradient from the humid region in SW-Hungary to the continental-semiarid region in NE Hungary where no forest intervention was applied during the last decades. Results outline that the health status of the stands in SW Hungary is between 70–80% while near to its xeric limit around 50%.

